CALIBRATION OF THE HCM 2010 SINGLE-LANE ROUNDABOUT CAPACITY EQUATIONS FOR GEORGIA CONDITIONS (PHASE 2)

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CALIBRATION OF THE HCM 2010 SINGLE-LANE ROUNDABOUT CAPACITY EQUATIONS FOR GEORGIA CONDITIONS (PHASE 2)

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To Mom and Dad, love you.

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LIST OF SYMBOLS

$c_{e,pce}$	Capacity of the approach lane under consideration in pce
n	Number of observations
t	Gap or lag
Δt	Adjustment time
T_1	Leading time stamp
T_2	Time stamp of the following circulating vehicle
t_c	Critical headway
t_f	Follow-up headway
$v_{c,pce}$	Conflicting flow in pce
v/c	Volume-to-capacity ratio

LIST OF ABBREVIATIONS

AADT	Average annual daily traffic
ALP01-SB	Alpharetta southbound
COL01-SEB	Columbus southeastbound
COL01-SWB	Columbus southwestbound
COV01-SB	Covington southbound
COV01-NB	Covington northbound
COV01-SB	Covington southbound
COV01-WB	Covington westbound
COV01-EB	Covington eastbound
CSV	Comma separated values
DOU01-EB	Douglasville eastbound
DOU01-WB	Douglasville westbound
DOU01-SB	Douglasville southbound
DOUL01-EB	Duluth eastbound
EMO01-SEB	Emory southeastbound
FAY01-EB	Fayetteville eastbound
FAY01-SB	Fayetteville southbound
FAY01-NB	Fayetteville northbound
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
HCM	Highway Capacity Manual
HIN01-WB	Hinesville westbound
HIN01-SB	Hinesville southbound

HOL01-EB	Holly Springs eastbound
HOL01-NB	Holly Springs northbound
LOS	Level of service
NCHRP	National Cooperative Highway Research Program
NEW01-EB	Newnan eastbound
NEW01-WB	Newnan westbound
pce	passenger car equivalents
PHF	Peak hour factor
QA/QC	Quality Assurance/Quality Control
ROS01-EB	Roswell eastbound (5/15/12)
ROS01-SWB	Roswell southwestbound (5/15/12)
ROS02-EB	Roswell eastbound (10/23/12)
ROS02-SWB	Roswell southwestbound (10/23/12)
STARS	State Traffic and Report Statistics
std. dev.	Standard Deviation
STS01-WB	St. Simons westbound
STS01-EB	St. Simons eastbound
TOPS	Wisconsin Traffic Operations and Safety
URA	Undergaduate research assistant
VIL01-SWB	Villa Rica southwestbound

SUMMARY

Roundabouts are becoming an increasingly appealing alternative intersection treatment because of their safety and efficiency benefits so much so that the Georgia Department of Transportation (GDOT) requires a roundabout be considered for every new or reconstructed intersection. One component of determining if a roundabout is a feasible intersection treatment is to perform an operational analysis. The operational performance of an existing or proposed roundabout can be assessed through capacity models. GDOT developed a Roundabout Analysis Tool which uses two different single-lane roundabout capacity models. The first model is the default single-lane roundabout capacity equation found in the 2010 Highway Capacity Manual (HCM). The second model is the 2010 HCM single-lane roundabout capacity equation calibrated with follow-up and critical headway values from California and Bend, Oregon. GDOT suggests that users of the spreadsheet use the first model, a more conservative model, because drivers in Georgia are not as familiar with roundabout as drivers in Oregon or California. In order to provide improved capacity predictions for existing and proposed Georgia roundabouts, the 2010 HCM roundabout capacity equations need to be locally calibrated based on Georgia drivers. The purpose of this study is to collect field data necessary to calculate follow-up and critical headways at Georgia roundabouts in order to calibrate the 2010 HCM capacity equations to yield improved capacity predictions. Also, this study will analyze the impact of including exiting vehicles in the roundabout analysis. Currently, the models in the GDOT Roundabout Analysis Tool do not include exiting vehicles.

This study used the methodology outlined in the NCHRP Report 572 as a guide. In order to measure follow-up and critical headway, operations at Georgia roundabouts were recorded with video cameras. The research team filmed 28 approaches at thirteen

Georgia roundabouts for a total of 56.5 hours. The video was processed manually using an in-house computer program. Based on analyst keystrokes during the video review the program would extract timestamps of events that are necessary for calculating follow-up and critical headway The NCHRP Report 572 presents several methods for calculating both follow-up and critical headway. Follow-up headway was calculated using the queued data method and the move-up time method. Critical headway was calculated using Method 1, 2, and 3 presented in the NCHRP Report 572. All methods and their results are presented in this report. The headway values presented in the final capacity equations used critical headway Method 2 and the follow-up headway move-up time method.

The follow-up and critical headway values were calculated for two different data sets: 1) including exiting vehicles and 2) excluding exiting vehicles. The critical and follow-up headway for an analysis including exiting vehicles is 4.192 seconds and 2.788 seconds respectively. The critical and follow-up headway for an analysis excluding exiting vehicles is 4.747 seconds and 3.265 seconds respectively. This study found that including the exiting vehicles impacts the capacity. The capacity increases or decreases based on the percentage of conflicting vehicles that are exiting vehicles. In addition, this study's calibrated model excluding exiting vehicles predicts higher capacity than the 2010 HCM model that GDOT recommends which also excludes exiting vehicles.

CHAPTER 1: INTRODUCTION

In the 1960s, the modern roundabout (hereafter referred to as just roundabout) was developed in Great Britain in response to the safety and efficiency issues of traffic circles [1]. The Highway Capacity Manual (HCM) 2010 defines roundabouts as, "intersections with a generally circular shape characterized by yield on entry and circulation around a central island (counterclockwise in the United States)" [2]. Figure 1 shows the general characteristics of a roundabout. In 1990, the first roundabout was constructed in the United States in Summerlin, Nevada [4]. Since then, roundabouts have become an increasingly appealing alternative intersection treatment because they are safe and efficient; however, the implementation of roundabouts has been limited because of insufficient information about the operational analysis and design guidelines of roundabouts.

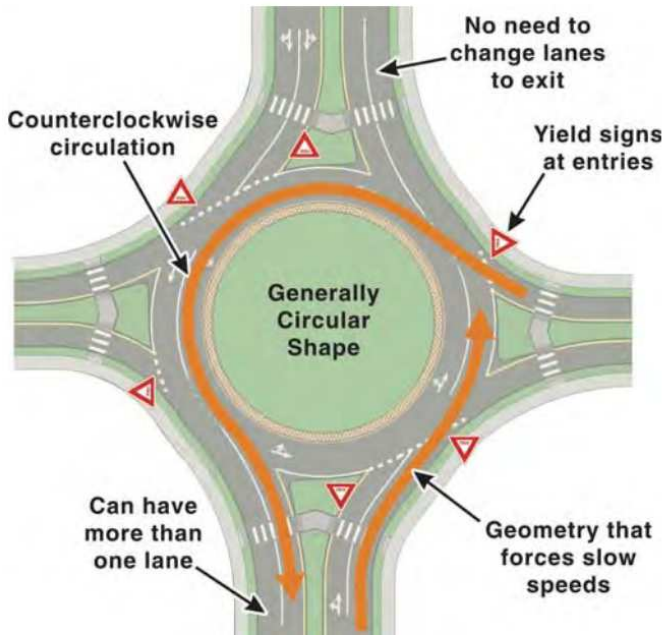


Figure 1. Characteristics of a modern roundabout (Rodegerdts et al. 2010)

In an effort to fill the void, several in-depth reports have recently been published to enhance the knowledge of designing and operating a roundabout. In 2000, the Federal

Highway Administration (FHWA) published *Roundabouts: An Informational Guide* (FHWA-RD-00-067) which includes guidelines for the planning phase, operational analysis, and design of roundabouts [5]. However, much of the report was based on European and Australian data because at the time there were only 38 roundabouts in the United States [3]. The documented benefits and outlined design guidelines of the 2000 FHWA report prompted the construction of many more roundabouts in the United States. The report was later updated in 2010 and published under the title *NCHRP Report 672 Roundabouts: An Informational Guide – Second Edition.*

In 2007, the *NCHRP Report 572: Roundabouts in the United States* was published. This document presented the safety and operational benefits of the newly expanded United States roundabout inventory. This report found that roundabouts are successful in a wide variety of environments in the United States including urban, suburban, and rural [1]. The report analyzed 55 sites before and after the installation of a roundabout. The results found the estimated percentage reduction in all crash and injury crashes were 35.4% and 75.8%, respectively [1]. In 2008, the FHWA released the Guidance Memorandum on Consideration and Implementation of Proven Safety Countermeasures, identifying roundabouts as one of nine safety countermeasures recognized and supported by FHWA [6]. This document states [6]:

> *Roundabouts are the preferred safety alternative for a wide range of intersections. Although they may not be appropriate in all circumstances, they should be considered as an alternative for all proposed new intersections on federally-funded highway projects, particularly those with major road volumes less than 90 percent of the total entering volume. Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements. This would include freeway interchange ramp terminals and rural intersections.*

The Georgia Department of Transportation (GDOT) also identifies roundabouts as the preferred safety alternative for intersections. As outlined in Chapter 8 of the GDOT Design Policy Manual [7],

> *a roundabout shall be considered in the following situations: for any intersection being designed on a new location or to be reconstructed; for any existing intersection that has been identified as needing major safety or operational improvement (or where improvements are otherwise planned); and for all intersections where a request for a traffic signal has been made.*

The feasibility of a roundabout is determined through multiple components including an operational analysis. The operational performance of an existing or proposed roundabout can be assessed through capacity models. The roundabout capacity models presented in NCHRP Report 572, Chapter 4 are used in the 2010 HCM.

The NCHRP Report 572 and 2010 HCM equations were used to develop the GDOT Roundabout Analysis Tool which analyzes the performance of single and multi-lane roundabouts. The tool's current calibration is based on data from California and Bend, Oregon [8]. In order to provide improved capacity predictions for existing and proposed Georgia roundabouts, the 2010 HCM roundabout capacity equations should be locally calibrated based on Georgia driver behavior and Georgia roundabout conditions. Georgia driver behavior is measured using the variables critical headway, or critical gap, and follow-up headway, or follow-up time. Roundabout conditions refer to traffic volumes and lane configuration. The capacity predictions will assist in the decision making process to build a single-lane roundabout, multi-lane roundabout, or determine if a roundabout is even a viable option.

This document is intended to:

1. calibrate the HCM 2010 single-lane roundabout capacity equations to Georgia conditions and drivers based on locally measured follow-up and critical headway,
2. provide a comparison of the different NCHRP methods for calculating critical and follow-up headway,
3. provide a comprehensive guide for data collection, data reduction, and data analysis that can be used for future replication of the calibration process, and

4. analyze the impact of including exiting vehicles in the roundabout capacity analysis.

CHAPTER 2: LITERATURE REVIEW

2.1 Previous Capacity Models

The first two roundabout capacity models for the United States were 1) the operational method presented in the FHWA *Roundabouts: An Informational Guide*, and 2) Troutbeck's gap acceptance method presented in the 2000 HCM [4]. However, at the time of these studies there were a limited number of roundabouts in the United States and further studies were later required with United States roundabout data.

2.1.1 FHWA Method

Three capacity equations were presented in the FHWA's *Roundabouts: An Informational Guide*. This method was based on data from Germany and the United Kingdom and served as a temporary method until US data could be obtained [5].

Urban Compact Roundabouts

The roundabout capacity equation for urban compact roundabouts is based on German capacity equations. The equation is as follows [5]:

$$q_{e,max} = 1218 - 0.74q_c, \text{ for } 0 \leq q_c \leq 1646 \quad \textbf{(1)}$$

Where:

$q_{e,max}$ = maximum entry flow, veh/h

q_c = traffic flow on the circulatory roadway, veh/h

Maximum entry flow refers to the maximum capacity of the roundabout approach under consideration. The traffic flow on the circulatory roadway refers to vehicles that are circulating in the roundabout past the approach of interest.

Single-lane Roundabouts

The roundabout capacity equation for single-lane roundabouts is based on Kimber's single-lane capacity equations found in *The Traffic Capacity of Roundabouts* a United Kingdom's study [9]. The equation is as follows [5]:

$q_{e,max} = \min[1212 - 0.5447q_c; 1800 - q_c]$, for $0 \leq q_c \leq 1800$ **(2)**

Where:

$q_{e,max}$ = maximum entry flow, veh/h

q_c = traffic flow on the circulatory roadway, veh/h

Multi-lane Roundabouts

The roundabout capacity equation for multi-lane roundabouts is also based on the findings in Kimber's *The Traffic Capacity of Roundabouts* [9]. The equation is as follows [5]:

$q_{e,max} = 2424 - 0.7159q_c$, for $q_c \geq 0$ **(3)**

Where:

$q_{e,max}$ = maximum entry flow, veh/h

q_c = traffic flow on the circulatory roadway, veh/h

2.1.2. 2000 HCM Method

The 2000 HCM presents Troutbeck's single-lane roundabout capacity model. This model was developed using a limited number of sites. This model is only applicable to single-lane roundabouts with a maximum circulating flow of 1200 vph. The equation is as follows [10]:

$$q_{e,max} = \frac{q_c e^{\frac{-q_c t_c}{3600}}}{1 - e^{\frac{-q_c t_f}{3600}}} \quad \textbf{(4)}$$

Where:

$q_{e,max}$ = maximum entry flow, veh/h

q_c = traffic flow on the circulatory roadway, veh/h

t_c = critical headway, seconds

t_f = follow-up headway, seconds

The 2000 HCM equation introduces two variables: critical headway and follow-up time. These variables are discussed in detail below.

Critical Headway, t_c

The 2000 HCM defines critical gap, or critical headway, as "the minimum time, in seconds, between successive major-stream vehicles, in which a minor-street vehicle can make a maneuver" [10]. In terms of a roundabout, the critical headway is the smallest gap an entering vehicle is willing to accept between two circulating vehicles. Critical headway cannot be field measured because it assumed that any observed gap acceptance will be larger than the critical headway. Therefore, critical headway is estimated based on the acceptance and rejection of gaps. Figure 2 provides an example of gap acceptance. In Figure 2, assume Vehicle A and Vehicle C are circulating in the roundabout and Vehicle B enters the roundabout between Vehicle A and Vehicle C. The gap Vehicle B accepts between Vehicle A and Vehicle C is greater than the critical headway. The 2000 HCM recommends a critical headway value between 4.1 and 4.6 seconds [10]. The value is selected based on driver behavior and gap acceptance characteristics. For example, a location with drivers who are familiar with roundabouts would use a critical headway closer to 4.1 seconds.

Follow-up Headway, t_f

The 2000 HCM defines follow-up time, or follow-up headway, as "the time span between the departure of one vehicle from the minor street and the departure of the next vehicle" [10]. In Figure 3 assume Vehicles A and B are entering the roundabout

consecutively. The follow-up headway is the time between Vehicle A entering the roundabout and Vehicle B entering the roundabout. The 2000 HCM found the upper and lower follow-up time values are 2.6 and 3.1 seconds respectively [10]. Like critical headway, the follow-up time would be selected based on driver behavior.

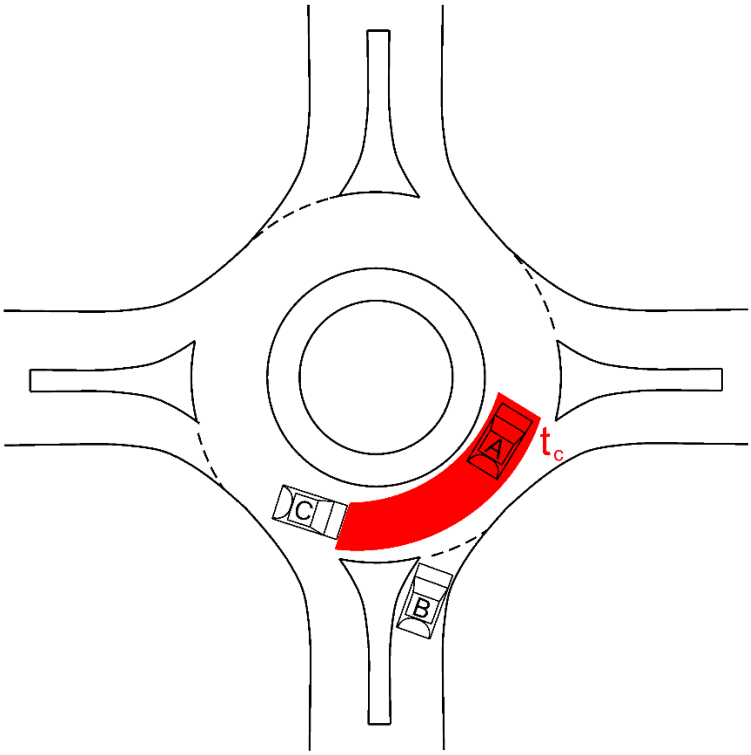


Figure 2. Critical headway example

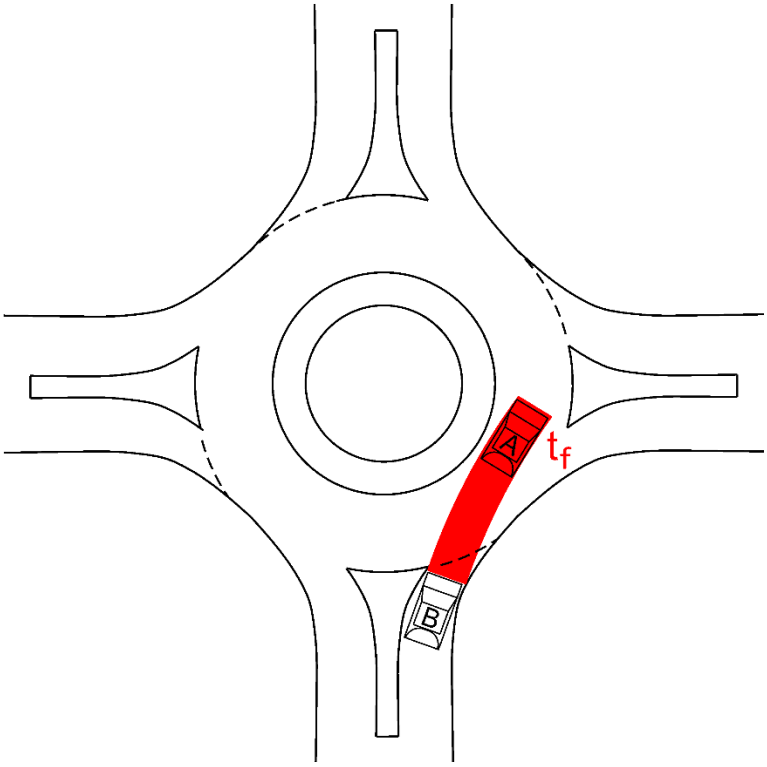


Figure 3. Follow-up headway example

2.2 Existing Capacity Models

The FHWA's operational method and the 2000 HCM's gap acceptance method were developed when roundabouts were in the early stages of implementation in the United States and there were few sites. The FHWA's *Roundabouts: An Informational Guide* was the first comprehensive roundabout resource that included information on the planning, operational analysis, and design of roundabouts in the United States. After the release of the guide, the number of roundabouts increased from 38 in 1997 to over 2,000 in 2010 [3]. Now with more available data the concept of roundabout capacity could be revisited this time with more sites and no longer the need to rely on foreign data and equations.

2.2.1 National Cooperative Highway Research Program (NCHRP) Studies

The NCHRP Project 3-65 Study entitled *Applying Roundabouts in the United States* was performed by Kittelson & Associates, Inc. [1]. One of the goals of the study was to gather operational field data from roundabouts in the United States and compare the data to the outputs of existing capacity equations [11]. This study also developed new capacity equations. The results of the NCHRP Project 3-65 are presented in the *NCHRP Report 572: Roundabouts in the United States* [1]. The NCHRP methodology for developing the capacity equations are outlined in the following sections along with the new capacity equations.

Screening Process

Kittelson & Associates, Inc. compiled a list of all known roundabouts in the United States at the time of study. The study took place from 2002 – 2004 and there were 310 known roundabouts in the United States that were considered modern roundabouts. In order to identify sites worthy of data collection, the following criteria had to be met [1]:

> *(1) an expectation of queuing on one or more of the roundabout approaches, representing capacity conditions;*
> *(2) a balance between single-lane and multilane sites so that operational characteristics of both kinds of sites could be studied;*
> *(3) a range of other geometric conditions so that the effect of these conditions on operations could be studied; [and]*
> *(4) a clustering of sites so that driving time to the sites could be minimized, thus maximizing the number of sites that could be studied.*

Kittelson & Associates, Inc. gathered data from 31 roundabout sites in ten states. The roundabouts were located in the following ten states: Colorado, Kansas, Maine, Maryland, Michigan, Nevada, Oregon, Utah, Vermont, and Washington [1]. At each site data was collected on the following roundabout features: setting, geometry, safety, operations, speed, pedestrian, and bicyclist.

Data Collection

The following operational data is required for predicting roundabout capacity: circulating traffic flow, follow-up headway, and critical headway. The circulating traffic flow is the only input for the roundabout capacity estimation equations. The follow-up and critical headways are used to calibrate the capacity equations to local drivers and conditions. Therefore, circulating traffic flow data and data used to calculate the follow-up and critical headway must be collected.

For the NCHPR Report 572, roundabouts were filmed using omni-directional cameras, masts, digital video cameras, and DVD recorders. The omni-directional camera was placed in the central island on top of a mast. The camera provided a 360-degree view of the roundabout. The digital cameras were used to capture the activity on the legs of the roundabout. After the approaches were filmed, a computer program was developed that allowed a user to watch the video and when a specific event occurred the user would press a keystroke and a timestamp would be recorded for that event. Figure 4 displays the location of where timestamps were collected. Each line corresponds to a specific event which is summarized in Table 1.

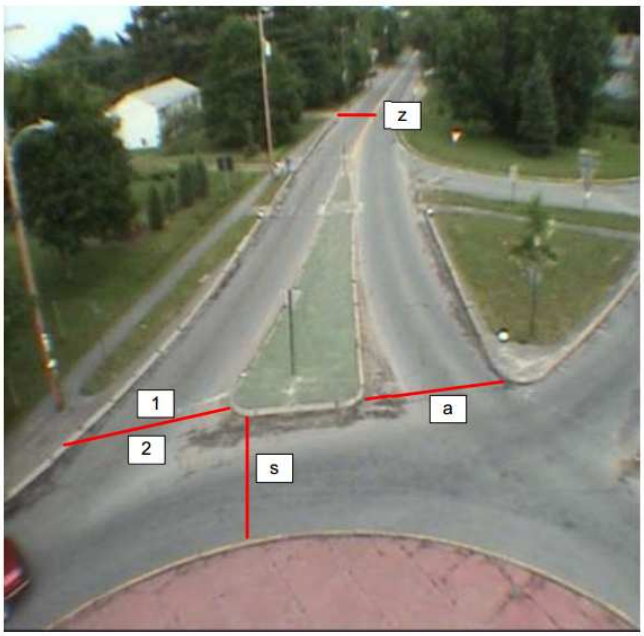


Figure 4. Timestamp collection locations (Rodegerdts et al. 2006)

Table 1. Events and corresponding keystrokes (Rodegerdts et al. 2006)

Event	Keystroke	Description
Entry time	2	The entry of a vehicle into the roundabout from the approach. The time was recorded when the vehicle crossed the yield line; the lane placement of the vehicle (either left lane or right lane) was recorded for two lane roundabouts. The vehicle type was also recorded.
First-in-queue time	1	The arrival of a vehicle into the server or first-in-line position on the approach. The time was recorded when the vehicle was about to enter the roundabout (if it did not stop) or the time that it stopped at or near the yield line waiting to enter the roundabout.
Upstream time	z	The passage of a vehicle past a point upstream of where a queue will form on the approach.
Conflict time	s	The passage of a vehicle through the conflict point on the roundabout, a point that is adjacent to the point of entry for a minor street vehicle.
Exit time	a	The exiting of a vehicle from the roundabout.

Data Reduction

Once the roundabout videos have been watched, data can be extracted from the timestamps. Data that is found from the timestamps are the circulating traffic flow, follow-up headway, and critical headway.

Circulating traffic flow: The circulating traffic flow is the number of vehicles circulating the roundabout past the approach of interest. The circulating traffic flow is simply found from summing the number of "s" keystrokes.

Follow-up headway: In order for a follow-up headway observation to be recorded, two vehicles must enter the roundabout in the same gap of circulating vehicles. The follow-up headway would be measured by subtracting the keystroke "2" timestamp of the first vehicle from keystroke "2" timestamp of the second vehicle. The NCHRP Report 572 calculates follow-up headway using two different methods: 1) queued data method and 2) move-up time data method. The queued data method is the average of the follow-up headway observations that occurred during queuing conditions that are at least a minute long. The requirement for queuing conditions ensures that the data used for analysis took place under near capacity conditions. However, at some locations there is not always consistent queuing. In many instances there are periods of queuing, but the periods are less than a minute long. Therefore, the concept of calculating follow-up headway based on move-up time was introduced in order to include follow-up observations that occurred during non-complete minutes of queuing [1].

Move-up time is the time it takes for one entry vehicle to replace the prior entry vehicle on the roundabout approach. For every follow-up headway value there is an associated move-up time value. The NCHRP Report 572 created a threshold value that was the 95^{th} percentile of all move-up times that occurred under queuing conditions [1]. If the move-up time for a follow-up headway observation was less than the threshold value this indicated a queuing event; therefore, the follow-up headway observation was included in the calculation of the average follow-up headway.

An example of how follow-up headway is calculated can be found in Appendix A. The NCHRP Report 572 found an average follow-up headway value of 3.4 seconds and 3.2 seconds using the queued data method and move-up time data method respectively [1]. The use of move-up time expanded the number of follow-up observations by almost

40%. The follow-up headway value the NCHRP Report 572 and 2010 HCM uses in their final model for single lane roundabouts is 3.2 seconds.

Critical headway: The critical headway is more complex to calculate. Since the critical headway is the smallest gap a vehicle is willing to accept, the critical headway cannot be observed in the field. It is assumed that the critical headway is smaller than the observed gap a vehicle accepts in the field. The NCHRP Report 572 presents the following three methods for determining critical headway [1]:

> *(1) inclusion of all observations of gap acceptance, including accepted lags;*
> *(2) inclusion of only observations that contain a rejected gap; and*
> *(3) inclusion of only observations where queuing was observed during the entire minute and the driver rejected a gap.*

In order to estimate the critical headway, the NCHRP Report 572 measures the gaps and lags an entering vehicle chooses to accept or reject. A gap is the time between two consecutively circulating vehicles. A gap is measured by subtracting subsequent timestamps at line "s". A lag is "the time from the arrival of the entering vehicle at the roundabout entry to the arrival of the next conflicting vehicle" [1]. A lag is measured by subtracting the timestamp of a circulating vehicle arriving at line "s" from the timestamp of a vehicle at line "1". Lags are only measured for Method 1. In order to include lags for Method 1 "the lags have been converted to gaps using an approximate follow-up headway" [1].

The NCHRP Report 572 uses the maximum likelihood method to estimate the critical headway. In a previous study, Troutbeck found that the maximum likelihood method is the most appropriate, low bias method [12]. The maximum likelihood method will be discussed in further detail in the methodology section of this report. The critical headway values for each NCHRP Report 572 critical headway method are summarized in Table 2. The table shows Method 1 has a smaller critical headway value than Method 2. This is because Method 1's average rejected gap is smaller than Method 2's average

rejected gap [1]. Also the number of observations decreased from Method 1 to Method 2 and from Method 2 to Method 3 because there are more requirements in Methods 2 and 3. The final capacity equation presented in the NCHRP Report 572 and 2010 HCM used critical headway Method 2 and a critical headway value of 5.0 seconds. Examples of how gaps and lags are measured for each of the three critical headway methods are found in Appendix A.

Table 2. NCHRP Report 572 critical headway values for each method

NCHRP Critical Headway Method	Critical Headway Value (seconds)	Number of Observations
Method 1	4.5	11,581
Method 2	5.0	3,322
Method 3	5.1	558

Data Analysis

After data reduction, the circulating traffic flow data was entered into the existing capacity equations to compare the capacity predictions to the collected field data. The existing capacity equations that were used for comparison were models from Australia, the United Kingdom, France, Germany, Switzerland, the 2000 HCM equation, and the FHWA's *Roundabouts: An Informational Guide* equation [1]. Figure 5 shows a comparison among all of the roundabout capacity predictions and the raw data for a single-lane roundabout located in Taneytown, Maryland. The raw data has been converted from one minute queued data to hourly capacities. As shown in the figure, the existing capacity models predicted higher capacities than the observed capacity. Similar results of higher predicted capacities than observed field data was consistent for all sites with the exception of two sites [1].

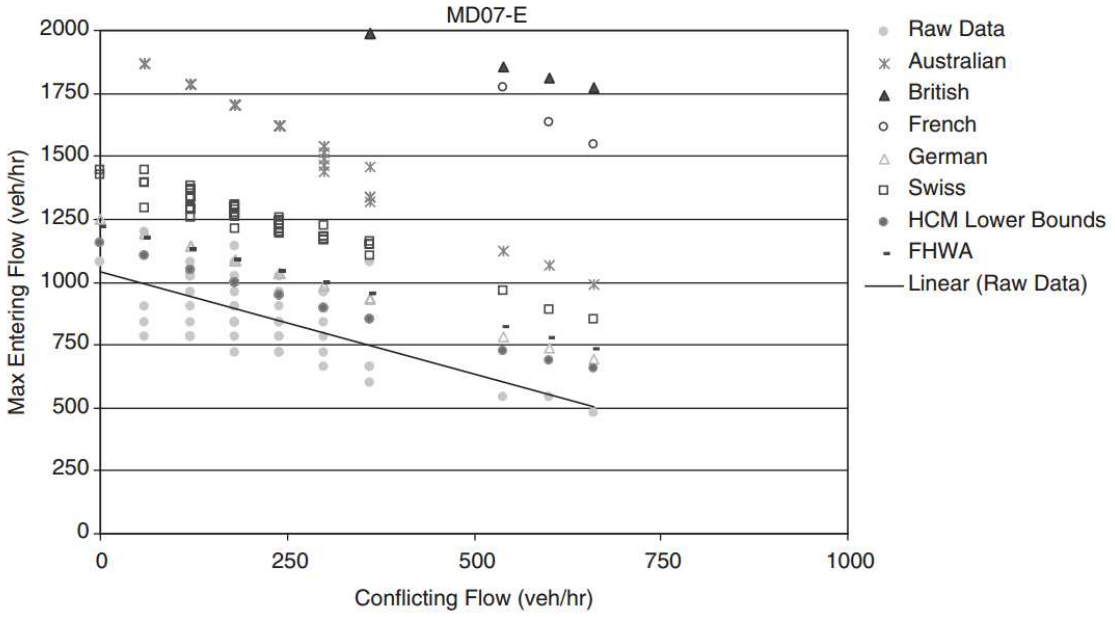


Figure 5. 2010 HCM uncalibrated entry capacity predictions with Taneytown, MD roundabout field data (Rodegerdts et al. 2007)

The study also found that the locally calibrated capacity equations yield more accurate capacity predictions than equations using default headway values [1]. The equations are calibrated using locally measured follow-up and critical headway values. The results of the NCHRP Report 572 study were presented in the 2010 HCM and the *NCHRP Report 672: Roundabouts: An Informational Guide* the 2nd edition. The final roundabout capacity prediction equations will be discussed in the next section.

2.2.2 2010 Highway Capacity Manual (HCM)

The results of the NCHRP Report 572 and NCHRP Report 672 are presented in Chapter 21 of the 2010 HCM [2]. Chapter 21 provides roundabout capacity prediction equations for single-lane roundabouts, multi-lane roundabouts, and roundabout slip lanes. This study is only concerned with single-lane roundabouts.

Single-lane roundabout

The single-lane roundabout equation is for roundabouts with a single circular roadway and a single-lane on each approach. An example of a single-lane roundabout is shown in Figure 6. Equation 5 is the equation for single-lane roundabout capacity [2]. The same equation can be applied to roundabouts with a single circular roadway and two approach lanes. A single-lane roundabout with two approach lanes is shown in Figure 7.

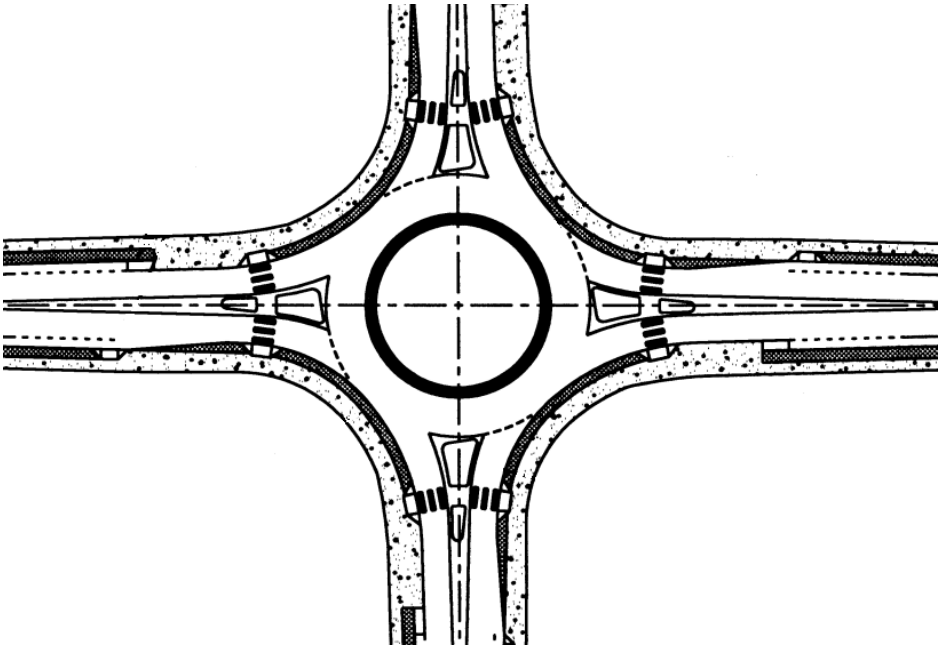


Figure 6. Single-lane roundabout (Robinson et al. 2000)

$$c_{e,pce} = 1130e^{(-1.0\times10^{-3})v_{c,pce}} \quad \textbf{(5)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

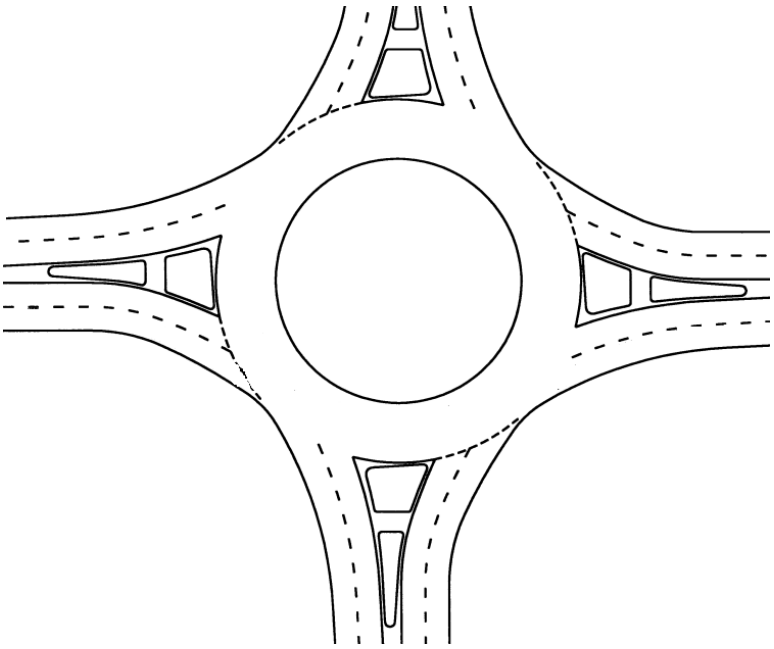


Figure 7. Single-lane roundabout with two-lane approaches (Robinson et al. 2000)

Multi-lane roundabout

The multi-lane roundabout equation is for roundabouts with two circular roadway lanes and one approach lane. An example of a multi-lane roundabout is shown in Figure 8. The north and south legs of the roundabout have one lane approaches. Equation 6 is the capacity equation for multi-lane roundabouts with one lane approaches [5].

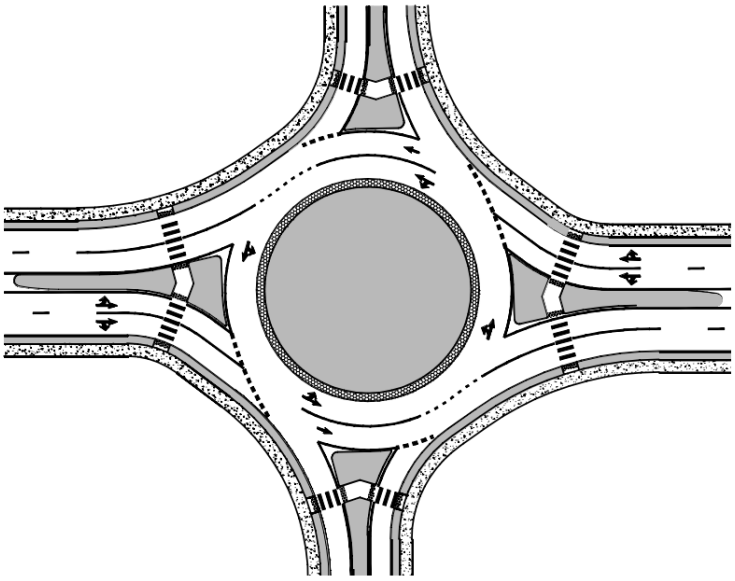


Figure 8. Multi-lane roundabout (Rodegerdts et al. 2010)

$$c_{e,pce} = 1130e^{(-0.7\times10^{-3})v_{c,pce}} \quad \textbf{(6)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

For multi-lane roundabouts with two circular roadway lanes and two approach lanes, two capacity equations are used. The east and west legs of the multi-lane roundabout shown in Figure 8 are two-lane approaches. The equation for the right approach lane is the same as Equation 6. The equations are the same because drivers heavily favor the right lane over the left-lane on two-lane approaches. The second equation is for the left approach lane which is Equation 7.

$$c_{e,pce} = 1130e^{(-0.75\times10^{-3})v_{c,pce}} \quad \textbf{(7)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

<u>Slip-lane roundabout</u>

The slip-lane capacity equation is for predicting the capacity of roundabout slip-lanes. Figure 9 shows a roundabout slip-lane on the south leg of the roundabout. There are two equations for slip-lane capacity. The first equation is for a single slip lane entering a single exiting lane. The equation for this scenario is the same as Equation 5.

The second equation is for a single slip lane entering two exiting lanes. The equation for this scenario is the same as Equation 6.

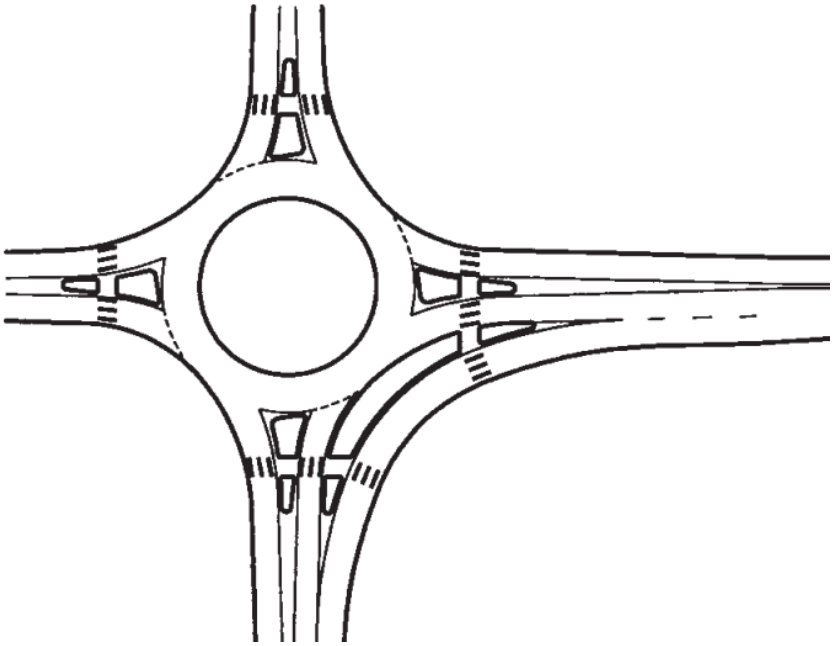


Figure 9. Roundabout with slip-lane on south leg (Robinson et al. 2000)

The equations presented above are calibrated to the NCHRP Report 572 data and require only the conflicting flow rate as input. However, the 2010 HCM presents the option of calibrating the above equations with local follow-up and critical headway values. For local conditions, the calibrated capacity equation is in the form found in Equation 8 and Equations 9 and 10 are for the input parameters. Therefore, follow-up and critical headway data must be collected in order to calibrate the capacity equation.

$$c_{pce} = Ae^{-Bv_c} \quad \textbf{(8)}$$

$$A = \frac{3600}{t_f} \quad \textbf{(9)}$$

$$B = \frac{t_c - \frac{t_f}{2}}{3600} \quad \textbf{(10)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

v_c = conflicting flow in passenger car equivalents, veh/h

t_c = critical headway, seconds

t_f = follow-up headway, seconds

2.3 Effect of Exiting Vehicles

When an entry vehicle is waiting to enter the roundabout on the approach, the driver is examining gaps they are willing to accept between circulating vehicles. The entering driver's decision is also impacted by the vehicles exiting the roundabout. Exiting vehicles are vehicles who exit the circulatory roadway at the approach of interest. The entering driver may hesitate to enter the roundabout until they know if the circulating vehicle is going to exit the roundabout or continue to circulate. The current HCM 2010 model does not include exiting vehicles in their capacity model. At the time the model was developed, the NCHRP Report 572 stated "the exiting flow does not impact all entering vehicles, and the exact extent of the influence of exiting vehicles has not been determined" [1]. However, a study performed by Mereszczak et al. found that capacity predictions are improved when exiting vehicles are included as part of the capacity prediction analysis [13].

When exiting vehicles are included in the analysis, the following three values are impacted: conflicting flow, follow-up headway, and critical headway. Prior to the inclusion of exiting vehicles, the conflicting flow variable only included circulating flow. The circulating flow includes vehicles that pass the approach of interest. For analyses including exiting vehicles, the conflicting flow variable is the sum of the circulating flow and the exiting flow. The exiting flow includes vehicles that exit at the approach of interest. For follow-up and critical headway, measurements must also be adjusted to

include the effect of exiting vehicles. For follow-up headway, the total number of observations decreases when exiting vehicles are included as exiting vehicles could disaggregate the gap between two consecutively entering vehicles. For example, if an exiting vehicle exits between two entering vehicles this is no longer considered a follow-up headway observation. For critical headway observations, Mereszczak et al. found that entering vehicles will treat every vehicle, exiting or circulating, in the circulatory roadway as a circulating vehicle until that vehicle exits or that vehicle makes their intention to exit known [13]. Therefore, the gap is impacted by exiting vehicles. The concept of projected travel time is used to incorporate exiting vehicles into calculating the gap. Projected travel time is the time it would take a vehicle to travel from the exiting vehicle timestamp collection location (the "a" event) to the circulating timestamp collection location (the "s" event) as shown in Figure 10.

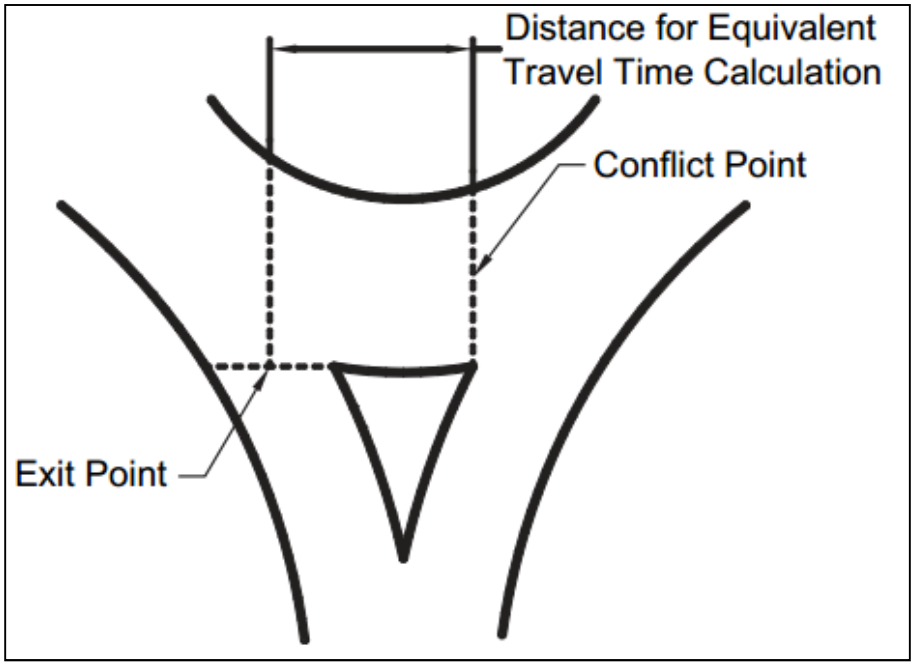


Figure 10. Projected travel time (Mereszczak et al. 2006)

A study performed by the Wisconsin Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin-Madison used Equation 11 to calculate

gaps/lags when exiting vehicles are considered in the analysis [14]. The projected travel time is added to the gap or lag only when the second vehicle, T_2, is an exiting vehicle. Figure 11 provides an outline for navigating what the adjustment time should be based on the vehicle type of T_1 and T_2 (i.e circulating, entering, or exiting). Appendix B provides a sample calculation for measuring the gap/lag when considering exiting vehicles.

$$t = T_2 - T_1 + \Delta t \quad \textbf{(11)}$$

Where:

t = Gap or lag (depends on what T_1, is), seconds

T_1 = Leading time stamp, seconds. When T_1 is the time stamp of a conflicting event or an exiting event as mentioned above, t is a gap; when T_1 is the time stamp of an arriving event, is a lag

T_2 = Time stamp or a conflicting event or an exiting event of the following circulating vehicle, seconds

Δt = Adjustment time, seconds. $\Delta t = 0$, when T_2 is the conflicting event; Δt = projected travel time, when T_2 is the exiting event.

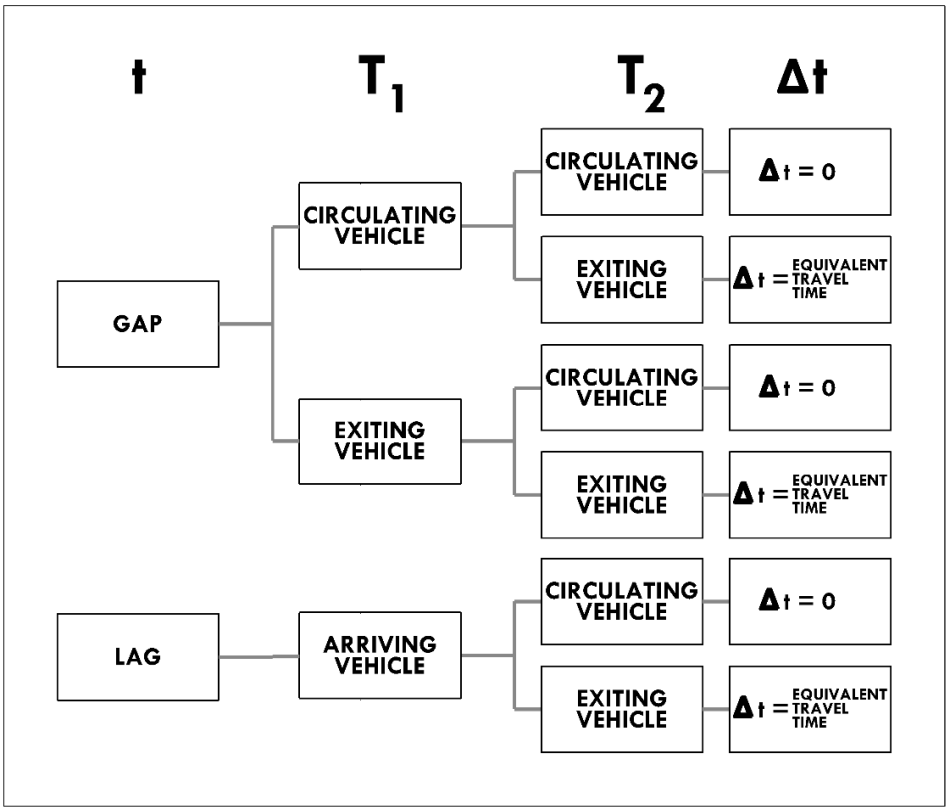


Figure 11. How to calculate adjustment time, Δt, based on T_1 and T_2 vehicle type

2.4 Past Calibration Efforts

This section provides examples of previous calibration studies. In each of these studies, the follow-up and critical headway values were measured locally and then applied to the roundabout capacity equations presented in the NCHRP Report 572.

2.4.1 Caltrans

In 2007, the University of Nevada calibrated the single and multi-lane roundabout capacity prediction equations presented in the NCHRP Report 572 for the California Department of Transportation (Caltrans) [15]. The research team studied nine single-lane roundabout sites in California and collected 18 hours of video. The research team followed the NCHRP Report 572 methodology to extract data. The team found critical headway values based on the NCHRP Report 572's critical headway Methods 1 and 2. In the end, the study used critical headway Method 2 and found an average critical headway

of 4.8 seconds [15]. The average follow-up headway is 2.5 seconds. When the follow-up and critical headway values are substituted into the NCHRP Report 572 single-lane capacity equation, shown as Equation 8 in this report, Equation 12 is obtained. Exiting vehicles were not considered in this study.

$$c_{e,pce} = 1440e^{(-0.001 \times v_{c,pce})} \quad \textbf{(12)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

2.4.2 Bend, Oregon

In 2010, Kittelson & Associates, Inc. calibrated the single and multi-lane roundabout capacity prediction equations outlined in the NCHRP Report 572 for The City of Bend, Oregon [16]. The team found an average follow-up headway of 2.7 seconds and an average critical headway of 4.1 seconds for single-lane roundabouts [16]. When the follow-up and critical headway values are substituted into the NCHRP Report 572 single-lane capacity equation, shown as Equation 8 in this report, Equation 13 is obtained. Exiting vehicles were not considered in this study.

$$c_{e,pce} = 1333e^{(-0.0008 \times v_{c,pce})} \quad \textbf{(13)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

2.4.3 Wisconsin

In 2011, the Traffic Operations and Safety (TOP) Laboratory at the University of Wisconsin-Madison calibrated the single and multi-lane roundabout capacity prediction equations outlined in the NCHRP Report 572 for Wisconsin Department of Transportation [14]. The team considered exiting vehicles in their analysis. The research team studied two single-lane roundabout sites in Wisconsin. The team found follow-up headway values of 2.6 and 3.8 seconds for each site. The critical headway values were 5.5 and 4.8 seconds for each site [14]. This study concluded that including exiting vehicles decreases the follow-up and critical headways.

2.5 GDOT Roundabout Analysis Tool

GDOT provides a Roundabout Analysis Tool to assist in the planning and design of a roundabout. The user inputs the following information: vehicle volumes per hour, peak hour factor (PHF), and percent of cars, heavy vehicles, bicycles, and pedestrians [8]. Given these inputs, the tool provides feedback on the predicted operations of the proposed roundabout along with a suggested geometric design.

The tool has the ability to forecast the operations of the roundabout and provides measures of effectiveness for each approach. These operational efficiency measures are capacity, volume-to-capacity (v/c) ratio, control delay, level of service (LOS), and queue length [8]. These operational measures, specifically the v/c ratio, control delay, and queue length, assist in determining the geometric design of the roundabout. For example, if the operational measures are at an unacceptable level the GDOT Roundabout Analysis Tool suggests adding a right turn bypass lane or making the single-lane roundabout a multi-lane roundabout.

The tool reports two sets of results in the spreadsheet. The first set of results is labeled “HCM 2010 Model (build)” and is based on the roundabout capacity model outlined in the HCM 2010. The HCM 2010 Model (build) uses the HCM 2010 default

follow-up and critical headway values, 3.2 and 5.0 seconds respectively. The second set labeled "Calibrated Model (future)" is the HCM 2010 model that was calibrated with data from Bend, Oregon and California. The calibrated model uses 2.7 and 4.1 for the follow-up and critical headway values respectively based on roundabouts in Bend, Oregon. In this instance, the calibrated results yield higher entry capacities than the non-calibrated results because the calibrated model uses lower headway values. The lower the headway values the higher the capacity.

GDOT suggests that users of the spreadsheet use the HCM 2010 Model (build) results because drivers in Georgia are not as familiar with roundabout as drivers in Oregon or California. The HCM 2010 Model (build) yields more conservative results than the Calibrated Model (future). GDOT suggests using the Calibrated Model (future) when roundabouts become more prominent in Georgia and Georgia drivers become more accustomed to driving in roundabouts. Table 3 provides a summary of the follow-up and critical headway values for all of the models discussed thus far. Figure 12 displays the capacity prediction models.

Table 3. Follow-up and critical headway values for various capacity prediction models

Model	Follow-up Headway (seconds)	Critical Headway (seconds)	Exiting vehicles considered?
Bend, Oregon/ GDOT Calibrated Model (future)	2.7	4.1	No
Caltrans	2.5	4.8	No
HCM 2010 Model/GDOT HCM 2010 Model (build)	3.2	5.0	No
Wisconsin			
Canal Street at 25th St.	2.6	5.5	No
	2.3	4.6	Yes
Sth 78 at CTH ID	3.8	4.8	No
	3.1	3.8	Yes

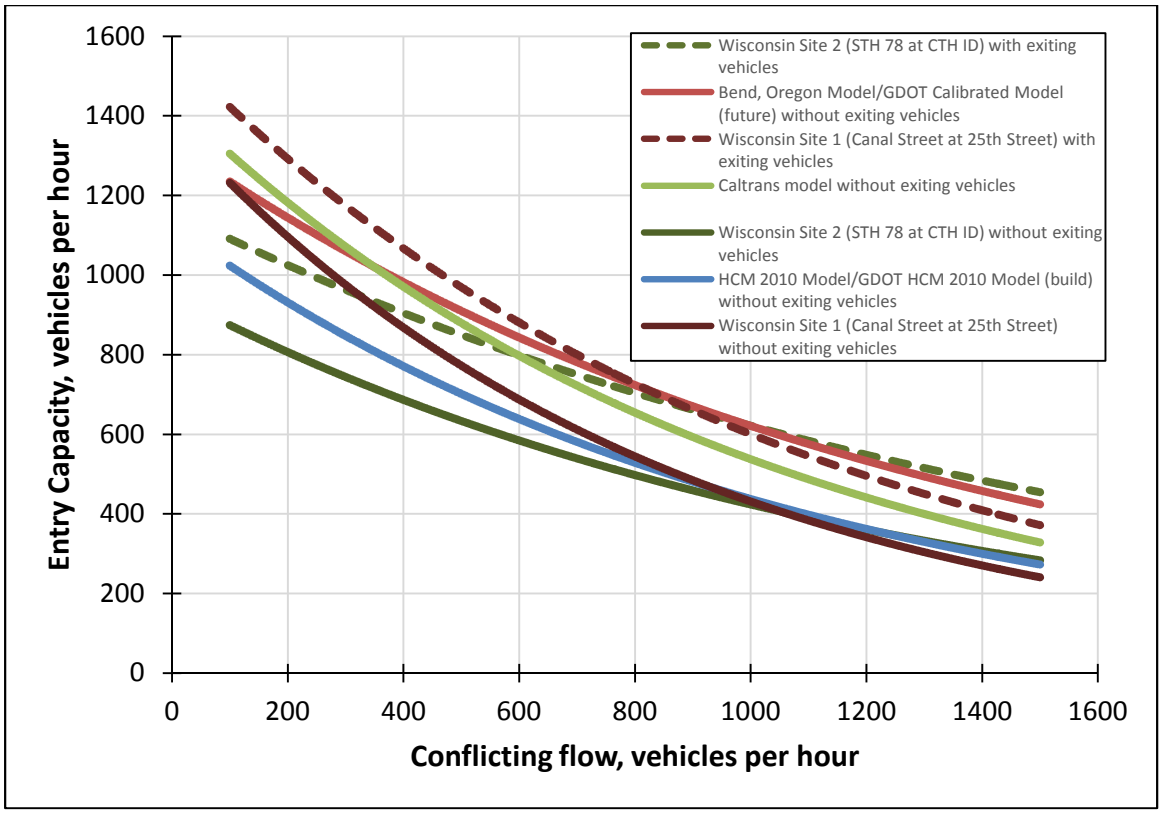


Figure 12. Comparison of entry capacity prediction models

This study will develop a model based on locally measured follow-up and critical headway of roundabouts in Georgia. Also, a comparison of the predicted capacities using the HCM 2010 Model (build), Calibrated Model (future), and this study's calibrated models will be presented. This study will also provide analysis with and without exiting vehicles to examine the impact of including exiting vehicles in capacity analysis. It is important to note that the current GDOT Roundabout Analysis Tool does not include exiting vehicles. The conflicting flow volume for the current model is the circulating vehicle volume only and does not include exiting vehicle volume.

CHAPTER 3: METHODOLOGY

This section presents a detailed account of the methodology used for this study to calibrate the HCM 2010 capacity prediction equations. First, an inventory of roundabouts in Georgia was created and data collection sites were selected. Then the research team collected field data by videotaping the identified collection sites. After data collection, a computer program was used to extract operational data from the roundabout videos. The data extracted from the videos was used to calculate follow-up and critical headway values. The values were then used to calibrate the HCM 2010 single-lane roundabout capacity prediction equations. The results of the newly calibrated capacity prediction equations are compared to the HCM 2010 default values. Figure 13 shows the steps that were followed to determine critical and follow-up headway values. The follow-up and critical headway values are calculated each with and without exiting vehicles. This section will provide a detailed description of each of the steps in the process.

3.1 Summary of Phase 1 Findings

The calibration of the HCM 2010 single-lane roundabout capacity equations for Georgia conditions was separated into two phases. The first phase was conducted by Barry [17] who established the methodology and performed an initial analysis. The second phase is this study which will provide a more inclusive analysis by determining follow-up headway and critical headway using all the methods presented in the NCHRP 572 Report. Barry observed 13 approaches at six roundabouts for a total of 29.5 hours. Barry performed two analyses: 1) including exiting vehicles and 2) excluding exiting vehicles. For follow-up headway, Barry found follow-up headway values under queued conditions and did not apply the move-up time method. The follow-up headway values including and excluding exiting vehicles were found to be 2.80 and 3.46 seconds

respectively [17]. Barry found critical headway using only NCHRP Report 572's critical headway Method 1. Method 1 includes both accepted/rejected gaps and lags; however, since the Phase 1 study the authors of NCHRP Report 572 have reported that Method 1 should not include accepted lags. The critical headway values including and excluding exiting vehicles were found to be 3.34 and 4.17 seconds respectively [17].

3.2 Step 1: Roundabout Site Selection

A selection process was developed in order to determine which roundabouts would be suitable sites for data collection. The selection process had two phases. The first phase was a broad sweep that identified the roundabouts in Georgia and then filtered out roundabouts with undesirable features. The second phase required a site visit to investigate the presence of queuing at the roundabout.

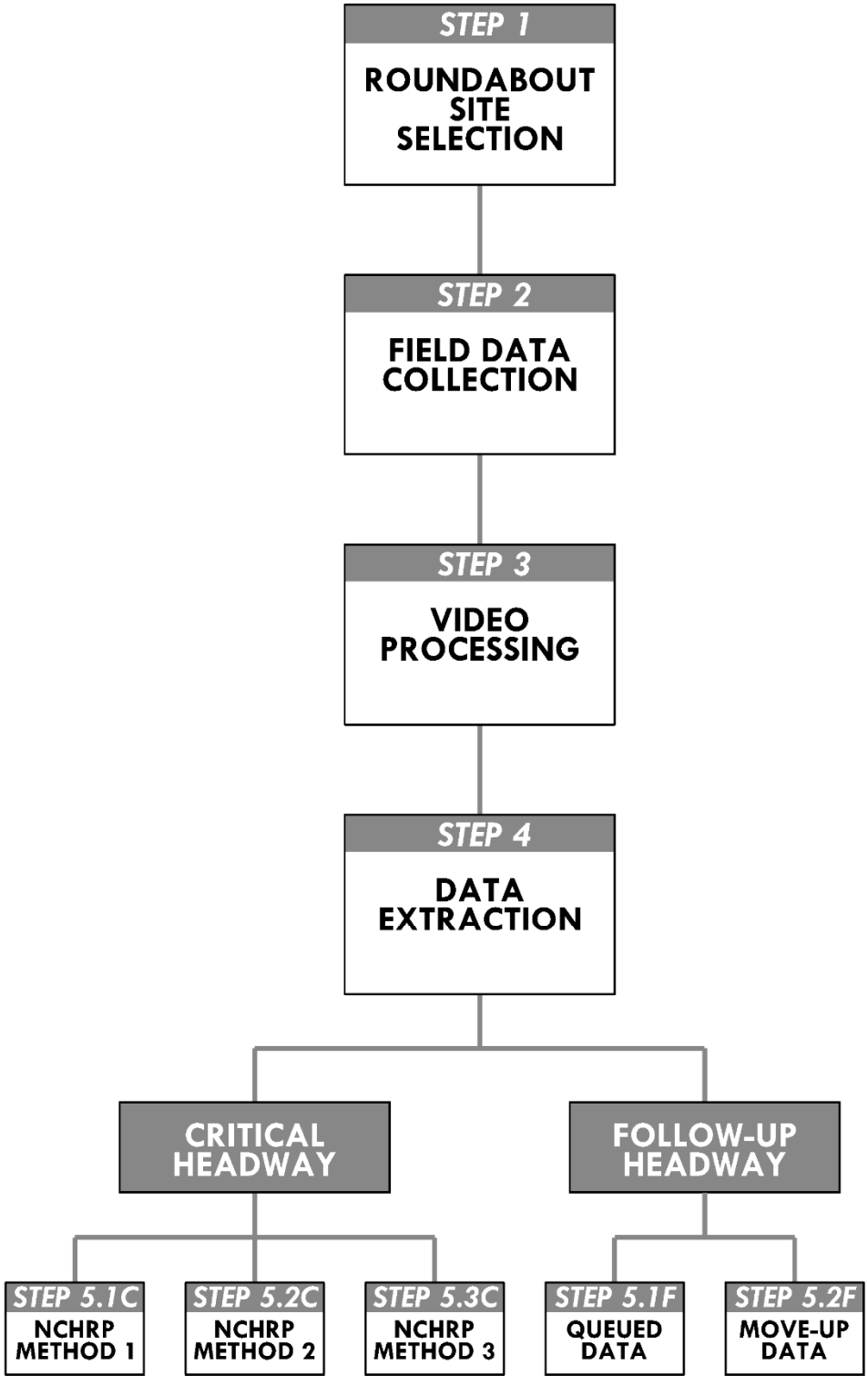


Figure 13. Steps for determining critical and follow-up headway

3.2.1 Phase 1

The first step was to create a roundabout inventory documenting all roundabouts in Georgia. An existing list was used as a starting point and then additional roundabouts were found by searching the news for recently constructed roundabouts. The research team identified over 100 roundabouts in the state of Georgia at the end of 2012; however, many of these roundabouts are low volume roundabouts located in residential areas.

Once all the roundabouts in Georgia were identified, the roundabouts were filtered through a series of criteria:

(1) High traffic volumes

(2) Modern roundabout features

(3) Age

High Traffic Volumes

The GDOT State Traffic and Report Statistics (STARS) was used to identify the annual average daily traffic (AADT) of the roundabout approaches where the data was available [18].

Modern Roundabout Features

Sites eligible for data collection had to have the modern roundabout features. Modern roundabout features include: splitter islands, truck aprons, pedestrian access, and proper signing and marking. Google Earth™ was used to inspect roundabouts for unusual geometric features [19]. For example, the circular intersection shown in Figure 14 does not have splitter islands; therefore, this site is not considered a modern roundabout. The modern roundabout features were the most important criterion when selecting roundabouts for data collection.

Figure 14. Example of a circular intersection without modern roundabout features

(Source: Google Earth™, accessed September 22, 2013)

Age of Roundabout

The research team preferred the roundabout site to have been constructed a least a year prior to data collection. Newly constructed roundabouts would most likely yield highly variable driver behavior data because local drivers would still be adapting to driving in the roundabout.

3.2.2 Phase 2

The outcome of the phase one selection process was a roundabout candidate list. Roundabouts on the list were visited to observe if there was consistent queuing on any of the approaches. The presence of queuing is necessary in order to collect data at roundabouts operating under capacity constrained conditions.

3.3 Step 2: Field Data Collection

A two person team was required for data collection. The team collected data during weekday AM peak hours, approximately 6:00 AM to 9:00 AM, and PM peak hours, approximately 4:00 PM – 7:00 PM. However, video recording was sometimes delayed or ended prematurely because of the lack of sunlight. The following equipment was required for data collection:

(1) 2 Panasonic HDC-TM700 video cameras

(2) 2 tripods with camera mounts

(3) 1 ladder 6’ – 8’

(4) 2 camera batteries

Since the research team had two cameras, the research team filmed two roundabout approaches at each data collection site. The camera was placed on the outside of the circulating roadway and out of the view of drivers as shown in Figure 15. The camera was positioned to capture the movements of entering, circulating, and exiting traffic on the approach of interest as shown in Figure 16. In addition, the camera had to capture far enough upstream of the roundabout entry in order to determine if there is queuing on the approach. Figure 17 shows the view from the camera.

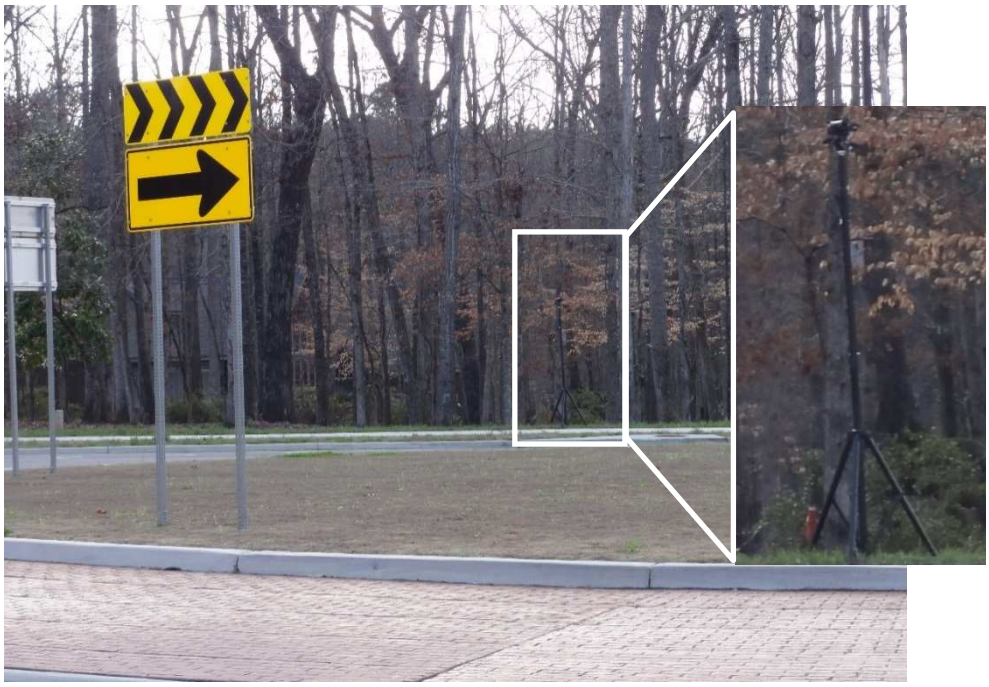


Figure 15. Camera setup for roundabout in Covington, Georgia

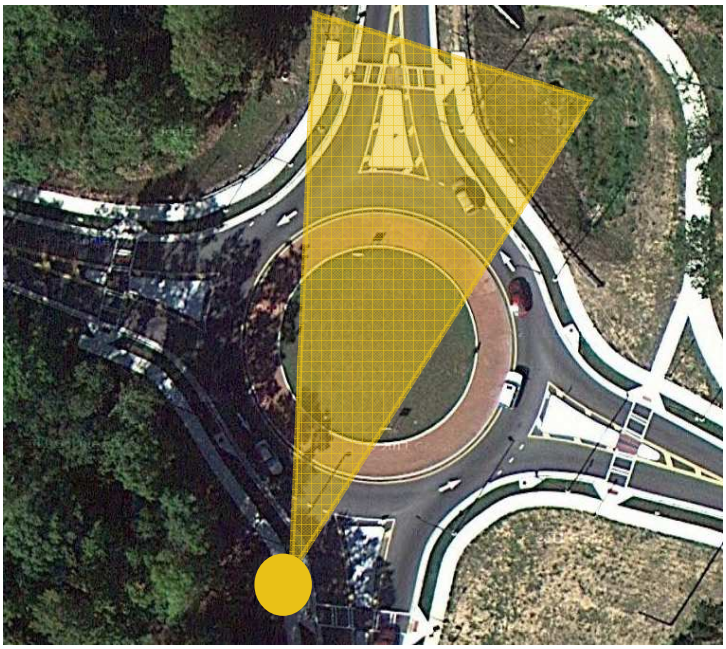


Figure 16. Camera placement for southbound approach for roundabout in Covington, Georgia

Figure 17. Camera view for southbound approach for roundabout in Covington, Georgia

3.4 Step 3: Video Processing

After data collection, the data required for calculating follow-up and critical headway needed to be extracted from the videos. In order to post-process the video, the video had to be converted from mts video format to an avi file video using FFmpeg, a conversion program (Zeranoe FFmpeg 2013). The data is extracted from the videos by collecting timestamps when certain events take place. The events of interest are the following:

(1) Vehicle arrives at the entry point

(2) Vehicle enters the circular roadway

(3) Vehicle exits the roundabout

(4) Vehicle circulates in front of the approach of interest

(5) Beginning of a queue on the approach of interest

(6) Ending of a queue on the approach of interest

Events 1-4 correspond to a particular location on the roundabout. Therefore, to eliminate ambiguity and ensure repeatability of the results, lines were drawn on the video to indicate the location of where timestamps for Events 1-4 should be collected. The lines were drawn on the video using AVS Video Editor by Online Media Technologies Ltd. [21]. The lines were drawn according to the example provided in the NCHRP Web-Only Document 94 shown in the Literature Review section of this report [4]. Figure 18 displays the location of the lines on the roundabout video. Each of the lines on the video corresponds to an event which is summarized in Table 4.

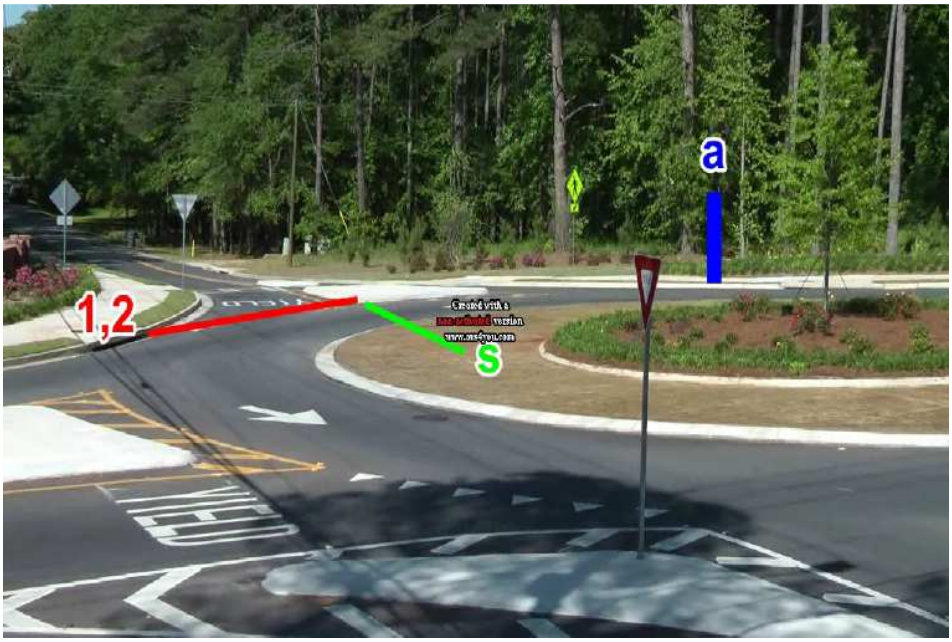


Figure 18. Location of timestamp data collection on southbound approach for roundabout in Fayetteville, Georgia

Table 4. Summary of keystrokes

Keystroke	Event
1	Vehicle arrives at the entry point
2	Vehicle enters the roundabout
a	Vehicle exits the roundabout
s	Vehicle circulates in front of the approach of interest
x	Beginning of queue on the approach
z	End of queue on the approach
q	Errors in the data collection file

Lakshmi Peesapati developed a Java program that collected timestamps corresponding to the events in Table 4 [22]. Undergraduate research assistants (URAs) would watch the roundabout video at real-time speed and enter the correct keyboard keystroke when an event occurred. Videos would range in length from one to three hours. URAs would watch the same video three times and collect different keystrokes each time through the video. The first time through the video keystrokes "1" and "2" were collected. Keystrokes "a" and "s" keystrokes were collected the second time. Finally, the third time through the video the keystrokes "x" and "z" were collected. The keystroke "q" was collected to denote a mistake during the data collection process. For example, if the URA identified a circulating vehicle as an exiting vehicle, the URA would immediately press "q" after making an incorrect keystroke. The mistake would later be resolved. The methodology described in the NCHRP Report 572 collects all keystrokes in a single pass through the video. After preliminary data collection, the research team found it very difficult to accurately record all the events of the vehicles in the roundabout as they occur in real-time in one pass through the video. Therefore, because collecting all data in one pass through the video yielded inaccurate results, the research team required data collection occur in three passes through the same video. The interface of the program is shown in Figure 19. Instructions for the data program provided to the URAs can be found in Appendix C.

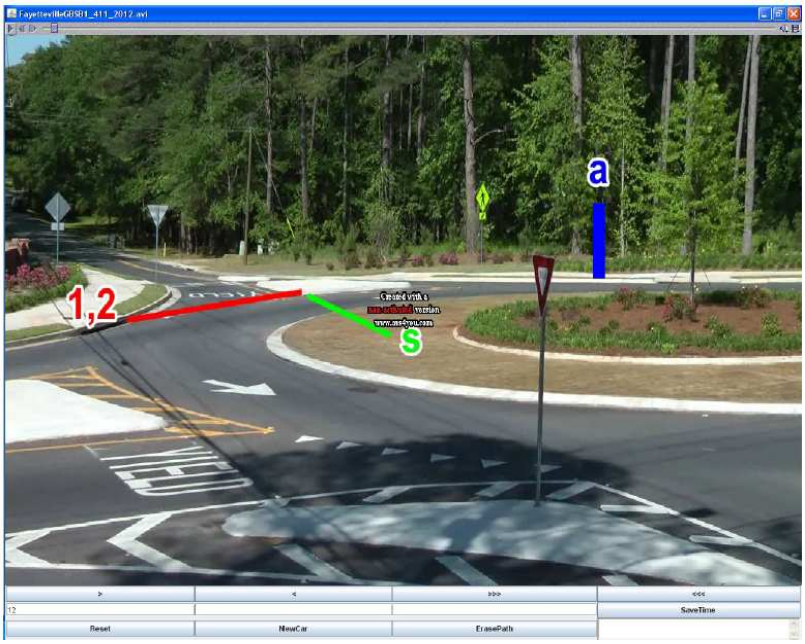


Figure 19. Interface of program used to collect timestamps

3.5 Step 4: Data Extraction

After each pass through the video, the program would write the timestamps directly to a comma separated values (CSV) text file. After the video was watched three times, an in-house developed Microsoft Visual Basic computer program was used to merge the three CSV files and sort the timestamps in order of smallest timestamp to largest timestamp. The merged and sorted keystroke file served as a log of all vehicle activity that took place in the roundabout in the order the events occurred. Once this log was created the program calculated the following values:

(1) Gap and lag data

(2) Queuing periods

(3) Move-up time

The values above are used to calculate follow-up and critical headway. The purpose of this section is to describe what data was extracted from the video processing

output files and how the above values were calculated. Approximately two and a half minutes of data from the roundabout site in Roswell, Georgia (ROS01-SWB) will be used as an example for sample calculations throughout this section of the report. This example does not include exiting vehicles. The three raw data outputs are shown in Appendix D.1. The merged and sorted data set is found in Appendix D.2.

3.5.1 Gap and Lag Data

Accepted/Rejected Gap Data

A gap is the time measured between two consecutive conflicting vehicles in a roundabout at some reference point [1]. The gap can be accepted or rejected by an entering vehicle. An accepted gap is when the following event sequence occurs: 1) the first vehicle circulates ("s" event), 2) entry vehicle enters the roundabout ("2" event), 3) the second vehicle circulates ("s" event). In other words, the entry vehicle accepts a gap when the entry vehicle enters the roundabout in-between the two circulating vehicles. If the entry vehicle does not enter the roundabout between the two circulating vehicles, the entry vehicle rejects the gap. The accepted/rejected gap is measured by finding the time between the first and second circulating vehicles at the line "s" location.

If exiting vehicles are included in the analysis, an accepted gap is when the following event sequence occurs: 1) the first vehicle circulates or exits ("s" or "a" event), 2) entry vehicle enters the roundabout ("2" event), 3) the second vehicle circulates or exits ("s" or "a" event). If the entry vehicle does not enter the roundabout between the two conflicting vehicles, the entry vehicle rejects the gap. The accepted/rejected gap is measured by finding the time between the first and second conflicting (circulating or exiting) vehicles at the line "s" or "a" location. The concept of projected travel time is used when the second vehicle of the gap is an exiting vehicle in order to project the timestamp of the exiting vehicle forward to the "s" line.

The projected travel time (Δt, Figure 10) was measured in a separate pass through each roundabout site video. Projected travel time was measured using the timestamps of when a circulating vehicle passed the “a” location and the “s” location. The projected travel time was found by subtracting the “a” timestamp from the “s” timestamp. For each roundabout site, the video was watched until twenty-five observations were measured

Rejected Lag Data

The NCHRP Report 572 defines a lag as “the time from the arrival of the entering vehicle at the roundabout entry to the arrival of the next conflicting vehicle” [1]. A rejected lag is when the following event sequence occurs: 1) entry vehicle arrives on the approach (“1” event) and 2) a vehicle circulates (“s” event). If exiting vehicles are included in the analysis, a rejected lag is when the following event sequence occurs: 1) entry vehicle arrives on the approach (“1” event) and 2) a vehicle exits (“s” or “a” event). Rejected lag is calculated by subtracting the arriving vehicle timestamp (the “1” event) from the conflicting event timestamp (“s” or “a” event). Rejected lag data is used when calculating critical headway according to Method 1. Based on a meeting with Kittelson & Associates, Inc. on June 20, 2013this study Method 2 does not utilize accepted lags.

3.5.2 Queuing Periods

Queuing periods are found to define when there are queuing conditions on the roundabout approach. These periods are based on observation. When queuing is present on the approach, the roundabout approach is operating at or near capacity constrained conditions. Therefore, data corresponding to events (i.e. entering, circulating, and exiting vehicle data) that occur under capacity constrained conditions is important to retain for the calculation of critical and follow-up headway. The purpose of defining queuing periods is to indicate data that will be utilized for the follow-up and critical headway determination.

A queuing period is bounded by the “x” event and the “z” event. The Microsoft Visual Basic® program extracts the timestamps of the “x” and “z” keystrokes to determine if the queuing period is at least a minute long. The NCHRP Report 572’s critical headway Method 3 and follow-up headway queued data method requires headway observations to take place during queuing periods lasting at least one minute [1]. The length of the queuing period is the difference in the timestamps of when the queue began (“x” event) and the time of when the queue ended (the “z” event). Queuing periods lasting at least a minute are used to indicate acceptable ranges of data when calculating critical and follow-up headway. It was not required that queuing periods began or ended on an integer minute.

3.5.3 Move-Up Time

Move-up time is the amount of time an entry vehicle takes to replace the prior entry vehicle at the roundabout approach. The move-up time is the difference between the first entry vehicle leaving the approach (“2” event) and the second entry vehicle arriving at the approach (“1” approach). Move-up time is used in the process of calculating follow-up headway. Specifically, move-up time is used to define queuing conditions and expand the number of follow-up headway observations whereas the queued data method defined queuing conditions based solely on observations

3.6 Step 5C: Critical Headway

The NCHRP Report 572 defines the critical headway as “the minimum headway an entering driver would find acceptable” [1]. Since critical headway is the minimum headway, it is assumed that any observed gap a driver accepts will be larger than the critical headway. Therefore, the critical headway cannot be observed in the field. The critical headway is estimated based on lag and gap acceptance. Once the gaps and lags

have been identified the Maximum Likelihood Method is used to find the critical headway value.

The Maximum Likelihood Method was used to perform a logistic regression on the accepted/rejected gaps and rejected lags. The likelihood function is the probability the average critical headway is between a driver's largest accepted gap and his largest rejected gap. In order to perform a logistic regression, the data must have a value of one or zero. Therefore, accepted gaps were assigned the value of one indicating a successful gap acceptance. Rejected gaps and rejected lags were assigned the value of zero indicating not a success of gap acceptance. The one and zero values were placed in a column labeled "Success" in the gap/lag data CSV file. This file was then input into the statistical software package "R" version 2.4.11 to perform the Maximum Likelihood Method [23]. Figure 20 shows a graph of the gap/lag data with assigned one and zero values.

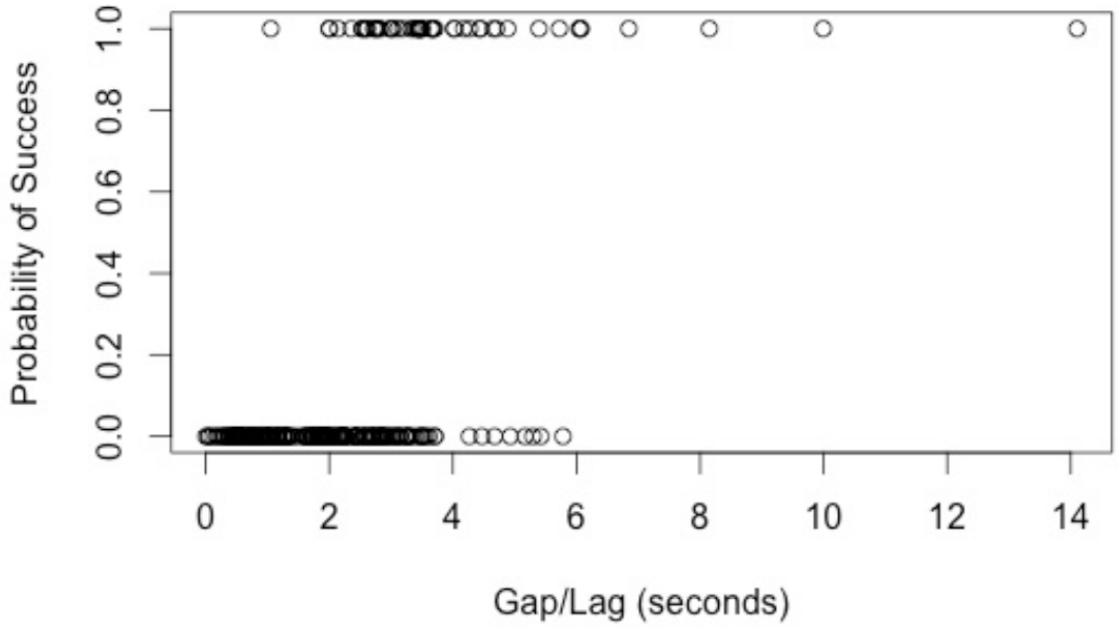


Figure 20. Gap and lag data plotted as one and zero values in R (Barry 2012)

The maximum likelihood for the critical headway is found at the inflection point of the logistic curve. This inflection point represents where the second derivative of the logistic equation is equal to zero. The logistic curve equation is found in R which has the form of Equation 14. The equation is shown below in Figure 21 displays the logistic regression with the inflection point. The inflection point is the critical headway value.

$$E\ (Y_i|X_i) = \frac{e^{\beta_0+\beta_1 X_i}}{1+e^{\beta_0+\beta_1 X_i}} \quad \textbf{(14)}$$

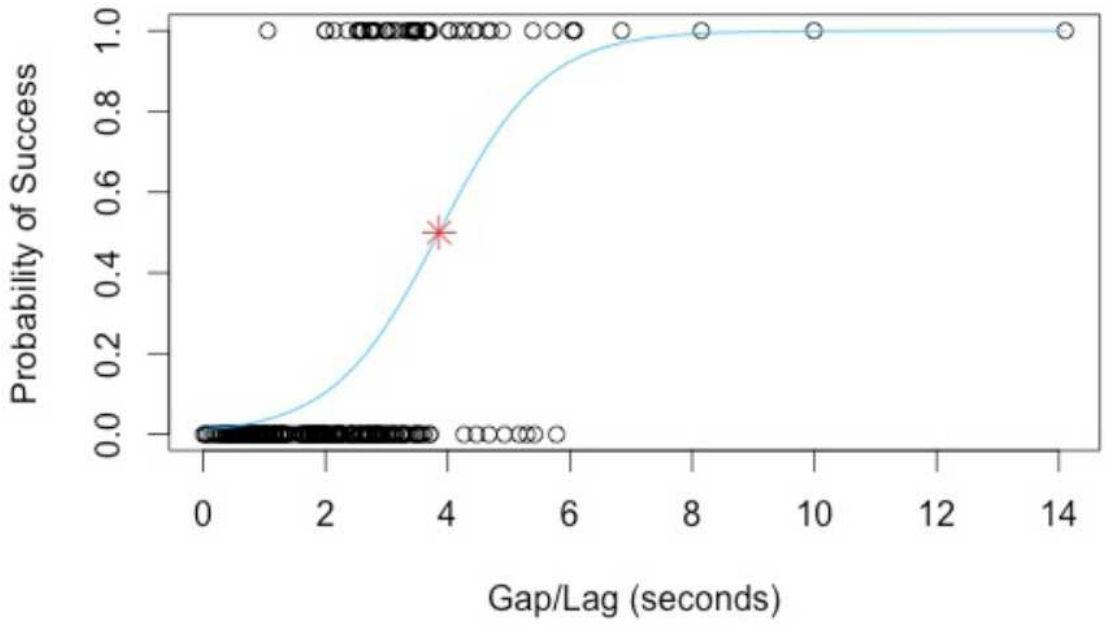


Figure 21. Logistic regression with inflection point (Barry 2012)

As mentioned in the Literature Review section of this report, the NCHRP Report 572 presents three methods for calculating critical headway. This study found critical headway values for each of the three NCHRP Report 572 methods using two different data sets: 1) with exiting vehicles and 2) without exiting vehicles. Each method is discussed in the sections below.

3.6.1 Step 5.1C: NCHRP Report 572 Critical Headway Method 1

The NCHRP Report 572 defines the first critical headway method as the "inclusion of all observations of gap acceptance, including accepted lags" [1]. However, on June 20, 2013, the research team met with Kittelson & Associates, Inc. who informed the team that NCHRP Report 572's method one for calculating critical headway should read as follows: inclusion of all observations of gap acceptance, including rejected lags. For this method, the data required to find critical headway is the accepted/rejected gaps and rejected lags. Appendix D.3 shows all the gap and lag data that would be used for this method for the sample data example. Once the gaps and lags have been identified, the Maximum Likelihood Method is used to determine the critical headway value.

3.6.2 Step 5.2C: NCHRP Report 572 Critical Headway Method 2

The NCHRP Report 572 defines the second critical headway method as the "inclusion of only observations that contain a rejected gap" [1]. For this method, that data required to find critical headway is the accepted/rejected gaps. However, for an accepted gap to be included in the calculation of critical headway the entry vehicle must reject at least one gap before it accepts a gap. Appendix D.4 shows all the gap data that would be used for this method for the sample data example. Once the gaps have been identified, the Maximum Likelihood Method is used to determine the critical headway value.

3.6.3 Step 5.3C: NCHRP Report 572 Critical Headway Method 3

The NCHRP Report 572 defines the third critical headway method as the "inclusion of only observations where queuing was observed during the entire minute and the driver rejected a gap" [1]. For this method, that data required to find critical headway is the accepted/rejected gaps and the queuing periods. In order for an accepted gap to be included in the calculation of critical headway the entry vehicle must reject at least one gap before he accepts a gap and the accepted/rejected gaps must occur under queuing

conditions that were at least a minute long. Appendix D.5 shows that for the sample data no gap data would be used for this method because none of the data met the criteria. Once the gaps have been identified, the Maximum Likelihood Method is used to determine the critical headway value.

3.7 Step 5F: Follow-up Headway

The NCHRP Report 572 defines follow-up headway as: "the headway maintained by two consecutive entering vehicles using the same gap in the conflicting stream. The entering vehicles must be in a queue" [1]. Follow-up headway is the time difference of first entry vehicle entering the roundabout (the "2" event) and the second entry vehicle entering the roundabout (the "2" event). Appendix D.6 displays the follow-up headway raw data observations. The NCHRP Report 572 finds follow-up headway using two different methods: 1) Queued Data Method and 2) Move-up Data Method.

3.7.1 Step 5.1F: Queued Data Method for Follow-up Headway

The Queued Data Method uses only follow-up observations that were observed during queuing conditions that were at least one minute long. This method reduces the number of follow-up headway observations that are included because there are few roundabout sites that are consistently under capacity constrained conditions. Appendix D.7 shows all the follow-up headway observations that would be used for this method for the sample data example.

3.7.2 Step 5.2F: Move-up Time Data Method for Follow-up Headway

The Move-up Data Method increases the number of follow-up headway observations by expanding the database using a move-up time threshold. For every follow-up time there is a corresponding move-up time. This method finds the 95^{th} percentile move-up time for all follow-up headway observations for all roundabout sites

during at least a minute of queuing conditions. This 95th percentile move-up time becomes a threshold. If the move-up time is less than or equal to the move-up time threshold then the associated follow-up time is included in the calculation of the average follow-up headway. The follow-up observation does not have to take place during a queuing period. The only criterion for including the follow-up headway observation is that the move-up time is less than the threshold. Appendix D.7 shows all the follow-up headway observations whose associate move-up time is less than or equal to the move-up time threshold.

3.8 Model Calibration

After the average critical and follow-up headways for each roundabout approach were found, a weighted average for the critical and follow-up headway values for all roundabout approaches was found. The weighted average is found by multiplying the average headway of the roundabout approach by the number of observations for that approach divided by the total number of all observations. Then the product of all roundabout approaches are added together to get the weighted average. Equation 15 is an equation for the critical headway weighted average. The critical and follow-up headway weighted averages are then substituted into the parameters equations for the HCM 2010 single-lane roundabout capacity equation. The parameter equations are Equations 9 and 10 in the Literature Review section. Then the parameter equations are substituted into the HCM 2010 single-lane roundabout capacity equation which is Equation 8 in the Literature Review section. After calibration, the only input required for the equation is the conflicting vehicle volume. If the analysis is considering exiting vehicles then the conflicting vehicle volume will include the both the circulating and exiting vehicle volume.

$$\mathrm{t_c} = \sum \left[t_{c_{ALP01-SB}} \times \left(\frac{n_{ALP01-SB}}{N} \right) \right] + \left[t_{c_{COV01-SB}} \times \left(\frac{n_{COV01-SB}}{N} \right) \right] + \left[t_{c_{COV01-NB}} \times \left(\frac{n_{COV01-NB}}{N} \right) \right] + \ldots \quad \textbf{(15)}$$

3.9 Quality Assurance/Quality Control

The Quality Assurance/Quality Control (QA/QC) process is important to ensure that the data reduction process can be duplicated and similar results are obtained regardless of the user. Two undergraduate research assistants (URA) were assigned to each roundabout video selected for data reduction. The primary URA records data for the entire video while the QA/QC URA records data for a randomly selected thirty minute subset of the video. The thirty minute subset is determined using a random number generator. Full length videos range in length from one to three hours. As mentioned in Step 3: Video Processing, the data collection procedure requires three passes through the video to collect the keystrokes.

A comma separated values text file (CSV) is generated for each pass through the video. Once all three passes are complete the three generated CSV files are merged and timestamps are sorted lowest to highest. The merged files of the primary and QA/QC URAs are compared to verify similar results. Only the same thirty minute segment of the primary URA is compared to the QA/QC's thirty minute data set. There are two types of values that are compared: 1) the timestamps and 2) the headway values.

For each keystroke type collected (i.e. "1", "2", "a", and "s"), the primary and QA/QC URAs' timestamps are compared to determine the average difference for each keystroke type. For example, suppose the average difference between the primary and URA timestamps for the "s" event is being calculated. All of the primary URA's timestamps for keystroke "s" are placed in one column of an Excel file. In another column are the QA/QC URA's timestamps for keystroke "s". In order to find the average difference for keystroke "s", the number of observations must be equal. The number of observations for each URA was checked to ensure they were equal. An unequal number of observations is indicative that one of the following scenarios occurred: 1) one URA missed an event or 2) one URA accidentally pressed a keystroke when an event did not occur. In the event that there are an unequal number of observations, the researcher

performing the QA/QC analysis must watch the roundabout video to determine which of the URAs' data sets is correct. Once the flawed data set has been identified, a third URA will redo either the primary or the QA/QC data collection whichever data set is incorrect.

Once it has been verified that both the primary and QA/QC URA have the same number of observations, the average difference can be calculated. For each occurrence of the "s" event, the difference between the timestamps corresponding to the "s" event is calculated. The average of the differences is found. This study determined a threshold of 0.2 seconds to be acceptable for the average difference. Therefore, if the average difference was greater than 0.2 seconds the researcher performing the QA/QC analysis would have to determine which data set was more accurate when compared to the video. The less accurate data set was thrown out and performed again by a third URA.

After the average difference in timestamps was compared, a second check was performed. The second check compared the follow-up and critical headway values. Follow-up and critical headway values were calculated using the above methodology for each of the primary and QA/QC URA thirty minute data sets. The acceptable difference in headway values was 0.2 seconds. However, during this check the research team found that in some instances the order of the keystrokes of the two URAs were not the same. Review of the data has shown that as all timestamps are not collected in one pass through the video it is possible that when the keystrokes are merged and sorted the order of the keystrokes could be different than the actual order of events based, based on differences in the URAs reaction time to the different events and selected keys. The URAs would have the same number of keystrokes for each type of event (i.e. both undergraduate's sample data contains the same number of exiting vehicles, circulating vehicles, etc.) which indicates both users accurately identified all events. However, when the .csv files are merged the outcome produces a different order of keystrokes. A different order in events would create different accepted/rejected gaps and lags.

The most prominent discrepancy between the two URAs is when a circulating vehicle arrives at the “s” location and an entering arrives at the “1” location at approximately the same time. One URA would believe the circulating vehicle arrived first while the second URA believed the entry vehicle arrived first. In this instance, a lag would be measured for the second URA and not for the first URA. Multiple instances of measuring different accepted/rejected gaps and lags affects the final critical headway values. Therefore, observations where a circulating vehicle and arriving entry vehicle occur in less than 0.1 seconds of each other were excluded in the thirty minute comparison analysis. By eliminating this scenario from the URAs thirty minute data sets, the remaining data in the primary and QA/QC URA data sets would have the same order of events. The same order of events meant the same accepted/rejected gaps and lags were being measured and allowed for a more meaningful comparison. This study recognizes this is not the ideal QA/QC method but believes this is the most comprehensive method considering a QA/QC method could not be found in past studies.

CHAPTER 4: RESULTS

4.1 Data Collection Sites

Table 5 displays all of the roundabouts where data was collected. A GDOT district map with the locations of all the data collection sites is located in Appendix E. In addition, Appendix F has summary sheets for all of the field data collected at each site and data extracted from post-processing the video.

Table 5. Roundabout data collection sites

Site	City	Lane Configuration			Collection Date	Approach	Time Duration (hr)	Site ID.
		Circulating Lanes	Legs	Slip Lanes				
Douglas Rd./Southlake Dr./Leeward Walk Cir.	Alpharetta	1	4	0	11/13/2012	SB	1:57	ALP01-SB
Turner Lake Rd. SW/Clark St. SW	Covington	1	4	0	3/1/2012	SB	2:33	COV01-SB
						NB	2:24	COV01-NB
					5/24/2012	WB	2:25	COV01-WB
						EB	2:11	COV01-EB
Warm Springs Rd./Blackmon Rd	Columbus	1	4	0	11/2/2012	SEB	1:39	COL01-SEB
						SWB	2:07	COL01-SWB
SR 166 (Duncan Memorial Hwy)/SR 5 (Bill Arp Rd.)	Douglasville	1	4	2	5/14/2012	EB	2:17	DOU01-EB
						WB	2:10	DOU01-WB
					11/1/2012	SB	1:27	DOU01-SB
N. Decatur Rd./Oxford Rd NE.	Atlanta	1	5	1	10/19/2012	SEB	1:49	EMO01-SEB
Grady Ave./Beauregard Blvd.	Fayetteville	1	4	1	4/11/2012	EB	2:04	FAY01-EB
						SB	2:02	FAY01-SB
					10/23/2012	NB	2:19	FAY01-NB
McClure Bridge Rd./W. Lawrenceville St./Irvindale Rd. NW	Duluth	1	3	0	6/1/2012	EB	1:49	DUL01-EB
N. Main St./Memorial Dr.	Hinesville	1	4	0	7/27/2012	WB	1:11	HIN01-WB
						SB	1:39	HIN01-SB
Holly Springs Rd./Davis Rd.	Marietta	1	4	0	10/11/2012	EB	1:58	HOL01-EB
						NB	1:52	HOL01-NB
Villa Rica/Sandtown	Marietta	1	4	0	3/27/2012	SWB	1:52	VIL01-SWB
E. Broad St./Greison Tr./E. Newnan Rd.	Newnan	1	4	0	10/25/2012	EB	1:55	NEW01-EB
						WB	1:52	NEW01-WB
Grimes Bridge Rd./Norcross St./Warsaw Rd./Melody Ln.	Roswell	1	5	2	5/15/2012	EB	2:06	ROS01-EB
						SWB	2:06	ROS01-SWB
					10/26/2012	EB	2:00	ROS02-EB
						SWB	2:00	ROS02-SWB
Lawrence Rd./Frederica Rd.	St. Simons	1	3	0	7/28/2012	WB	2:52	STS01-WB
						EB	2:08	STS01-EB
						Total	**56:44:00**	

4.2 Critical Headway

For each roundabout site, critical headway values were calculated using a data set with exiting vehicle data and a data set without exiting vehicle data. For each of these two data sets three critical headway values were found using each of the three NCHRP critical headway methods. Therefore, for each roundabout site six critical headway values were found.

For critical headway analysis including exiting vehicles the, Wisconsin projected travel time method was used in projecting the exiting vehicles forward. The projected travel times for each site are shown in Table 6. Table 7 displays the critical headway values including exiting vehicles for each of the three NCHRP critical headway methods. The critical headway values for Methods 1, 2, and 3 are 4.277, 4.192, and 4.270 seconds respectively when including exiting vehicles in the data analysis. It is expected that the critical headway for Method 3 be lower than the critical headway for Method 2 because under the queuing conditions, which are required for Method 3, the vehicles in a queue have more urgency to accept gaps [1]. However, the critical headway for Method 3 is slightly larger than Method 2 by approximately 0.1 seconds. Table 8 displays the critical headway values excluding exiting vehicles for each of the three NCHRP critical headway Methods. The critical headway values for methods 1, 2, and 3 are 5.503, 4.747, and 4.922 seconds respectively.

Table 6. Projected travel time measured for roundabout sites

Site	Projected Travel Time (seconds)
ALP01-SB	0.902
COV01-SB	1.549
COV01-NB	1.493
COV01-WB	2.323
COV01-EB	1.244
COL01-SEB	1.374
COL01-SWB	1.309
DOU01-EB	0.615
DOU01-WB	0.893
DOU01-SB	1.355
EMO01-SEB	1.292
FAY01-EB	1.290
FAY01-SB	1.463
FAY01-NB	1.481
DUL01-EB	2.229
HIN01-WB	1.317
HIN01-SB	1.161
HOL01-EB	0.250
HOL01-NB	2.263
VIL01-SWB	0.910
NEW01-EB	0.965
NEW01-WB	1.958
ROS01-EB	0.927
ROS01-SWB	1.212
ROS02-EB	1.043
ROS02-SWB	1.291
STS01-WB	1.177
STS01-EB	0.861

Table 7. Critical headway with exiting vehicles

Sites	NCHRP Method 1[1]			NCHRP Method 2[2]			NCHRP Method 3[3]		
	t_c (s)	n	std. dev.	t_c (s)	n (% of NCHRP Method 1)	std. dev.	t_c (s)	n (% of NCHRP Method 1)	std. dev.
ALP01-SB	3.734	879	1.3	3.467	341 (39%)	1.3	2.960	26 (3%)	0.9
COV01-SB	3.943	1208	1.3	3.755	213 (18%)	1.1	3.715	186 (15%)	1.1
COV01-NB	4.109	1406	1.3	4.138	327 (23%)	1.6	4.158	171 (12%)	1.4
COV01-WB	4.800	642	1.9	4.774	222 (35%)	1.7	4.133	11 (2%)	1.3
COV01-EB	4.759	399	1.8	4.808	253 (63%)	1.9	6.743	35 (9%)	1.8
COL01-SEB	4.851	429	1.9	4.538	135 (31%)	1.9	3.833	8 (2%)	1.1
COL01-SWB	4.404	425	1.8	4.297	89 (21%)	1.7	4.208	5 (1%)	1.1
DOU01-EB	4.096	313	1.9	3.520	78 (25%)	1.7	n/a	0 (0%)	n/a
DOU01-WB	4.549	215	1.8	3.974	29 (13%)	1.9	n/a	0 (0%)	n/a
DOU01-SB	4.010	91	2.2	3.733	18 (20%)	1.6	n/a	0 (0%)	n/a
EMO01-SEB	4.961	1051	1.5	4.834	423 (40%)	1.4	5.241	224 (21%)	1.4
FAY01-EB	4.613	414	1.9	4.230	100 (24%)	1.6	3.956	16 (4%)	0.7
FAY01-SB	5.260	271	2.0	4.363	43 (16%)	2.2	3.708	5 (2%)	1.8
FAY01-NB	4.590	437	1.8	4.739	116 (27%)	1.8	7.211	14 (3%)	2.1
DUL01-EB	5.478	127	1.7	5.322	14 (6%)	1.3	n/a	0 (0%)	n/a
HIN01-WB	5.149	71	2.1	3.957	21 (30%)	2.2	n/a	0 (0%)	n/a
HIN01-SB	5.258	123	2.0	5.528	14 (11%)	2.1	n/a	0 (0%)	n/a
HOL01-EB	4.522	146	2.0	4.434	56 (38%)	1.8	n/a	0 (0%)	n/a
HOL01-NB	4.727	444	1.8	4.638	249 (56%)	1.7	4.111	7 (2%)	1.0
VIL01-SWB	4.038	430	1.4	3.384	50 (12%)	1.2	4.001	7 (2%)	1.0
NEW01-EB	4.647	215	2.1	5.045	64 (30%)	2.1	n/a	0 (0%)	n/a
NEW01-WB	4.711	421	1.7	4.276	66 (16%)	1.8	4.138	12 (3%)	1.3
ROS01-EB	3.313	784	1.2	3.389	179 (23%)	1.2	3.655	35 (4%)	0.9
ROS01-SWB	3.926	705	1.6	3.817	191 (27%)	1.5	3.906	78 (11%)	1.3
ROS02-EB	3.633	664	1.3	3.338	203 (31%)	1.2	3.227	28 (4%)	1.2
ROS02-SWB	3.863	849	1.5	3.780	217 (26%)	1.3	3.648	132 (16%)	1.1
STS01-WB	5.587	44	2.7	5.517	15 (34%)	2.5	n/a	0 (0%)	n/a
STS01-EB	5.431	36	2.5	6.030	9 (25%)	2.9	n/a	0 (0%)	n/a
Total		13239			3739 (28%)			1000 (8%)	
Average (weighted)	4.277		2.136	4.192		2.039	4.270		1.315

Legend: n = number of observations; t_c = critical headway; std. dev. = standard deviation

[1]All observations of gap acceptance (accepted/rejected gaps and rejected lags)

[2]Observations that include a rejected gap

[3]Observations that include a rejected gap and occur during user defined queuing periods > 1 min

Table 8. Critical headway without exiting vehicles

Sites	NCHRP Method 1[1]			NCHRP Method 2[2]			NCHRP Method 3[3]		
	t_c (s)	n	std. dev.	t_c (s)	n (% of NCHRP Method 1)	std. dev.	t_c (s)	n (% of NCHRP Method 1)	std. dev.
ALP01-SB	6.018	321	2.2	5.299	56 (17%)	2.3	3.623	7 (2%)	1.4
COV01-SB	6.533	330	1.5	3.464	4 (1%)	1.8	n/a	0 (0%)	n/a
COV01-NB	6.784	263	2.0	4.366	12 (4%)	2.9	4.918	8 (3%)	3.1
COV01-WB	4.957	471	2.0	4.330	129 (27%)	1.9	4.263	10 (2%)	1.1
COV01-EB	4.932	370	2.0	4.949	232 (62%)	2.1	7.028	33 (9%)	2.0
COL01-SEB	6.145	222	2.1	4.382	16 (7%)	2.1	4.318	6 (3%)	1.0
COL01-SWB	5.414	157	2.0	3.781	17 (11%)	2.1	n/a	0 (0%)	n/a
DOU01-EB	6.367	131	2.3	4.876	12 (9%)	2.6	n/a	0 (0%)	n/a
DOU01-WB	5.290	162	1.8	4.980	10 (6%)	2.0	n/a	0 (0%)	n/a
DOU01-SB	6.023	34	2.7	n/a	0 (0%)	n/a	n/a	0 (0%)	n/a
EMO01-SEB	5.555	877	1.7	5.175	284 (32%)	1.7	5.134	157 (18%)	1.5
FAY01-EB	6.108	246	2.2	4.938	33 (13%)	2.4	3.814	7 (3%)	0.9
FAY01-SB	5.664	216	2.0	4.974	25 (12%)	2.3	4.136	3 (1%)	2.0
FAY01-NB	6.327	221	2.1	5.291	21 (10%)	2.4	n/a	0 (0%)	n/a
DUL01-EB	7.852	13	2.3	n/a	0 (0%)	n/a	n/a	0 (0%)	n/a
HIN01-WB	6.204	51	2.5	5.244	13 (25%)	2.5	n/a	0 (0%)	n/a
HIN01-SB	7.111	65	2.1	6.339	3 (5%)	1.2	n/a	0 (0%)	n/a
HOL01-EB	5.183	125	2.2	4.876	39 (31%)	2.0	n/a	0 (0%)	n/a
HOL01-NB	4.621	362	1.9	4.487	176 (49%)	1.8	3.038	4 (1%)	1.4
VIL01-SWB	6.667	184	1.9	4.521	6 (3%)	1.6	5.333	2 (1%)	0.7
NEW01-EB	5.974	117	2.5	4.883	9 (8%)	2.6	n/a	0 (0%)	n/a
NEW01-WB	5.587	221	1.8	4.538	16 (7%)	2.2	n/a	0 (0%)	n/a
ROS01-EB	6.417	167	1.6	3.736	4 (2%)	1.3	n/a	0 (0%)	n/a
ROS01-SWB	4.138	538	1.8	4.230	104 (19%)	1.7	4.530	38 (7%)	1.6
ROS02-EB	6.234	152	1.9	4.557	2 (1%)	2.8	n/a	0 (0%)	n/a
ROS02-SWB	4.443	660	1.7	4.064	112 (16%)	1.6	4.032	58 (9%)	1.5
STS01-WB	6.567	29	3.0	7.733	9 (31%)	2.6	n/a	0 (0%)	n/a
STS01-EB	7.079	19	2.7	n/a	0 (0%)	n/a	n/a	0 (0%)	n/a
Total		6724			1344 (20%)			333 (5%)	
Average (weighted)	5.503		1.916	4.747		1.922	4.922		1.562

Legend: n = number of observations; t_c = critical headway; std. dev. = standard deviation

[1]All observations of gap acceptance (accepted/rejected gaps and rejected lags)

[2]Observations that include a rejected gap

[3]Observations that include a rejected gap and occur during user defined queuing periods > 1 min

The critical headway values that will be used in this study's capacity equations are weighted average values calculated using NCHRP's critical headway Method 2. This method was selected because "Method 2 is the recommended methodology" [1]. Table 9 shows the average, weighted average, and median critical headway values for all sites. This study chose to use the weighted average critical headway values, 4.192 and 4.747 seconds for data sets with and without exiting vehicles respectively, from the list with all site locations.

Table 9. Critical headway values for all sites using NCHRP Report 572 critical headway Method 2

	ALL 28 APPROACHES	
	With exiting	Without exiting
Average (s)	4.344	4.445
Weighted average (s)	**4.192**	**4.747**
Median (s)	4.230	4.938
n	3739	1344

4.3 Follow-up Headway

For each roundabout site, follow-up headway values were calculated using a data set with exiting vehicle data and a data set without exiting vehicle data. For each of these two data sets, two follow-up headway values were found using the NCHRP Report 572's queued data method and move-up time method. Therefore, for each roundabout site, four critical headway values were found. Since many of the roundabout sites did not have consistent queuing, the move-up time method was used to expand the number of follow-up observations. For every follow-up headway observation there is an associated move-up time. One move-up time threshold was established for the data set with exiting vehicles and another move-up time threshold was established for the data set without exiting vehicles. The move-up time threshold is found from the 95th percentile of move-

up time observations of the queued data (i.e. move-up time observations that took place under at least a minute of queuing for all sites).

Two different move-up times are established because not all follow-up headway observations will be included in both the including and excluding vehicle data analysis. The follow-up headway observations including exiting vehicles will be a subset of the follow-up headway observations of the excluding exiting vehicle data. There are fewer follow-up headway observations when exiting vehicles are included because exiting vehicles will create more gaps to prevent two entering vehicles to enter the roundabout consecutively in the same gap. Consider the following scenario: 1) a vehicle enters the roundabout ("2" event), 2) a vehicle exits ("a" event), and 3) a vehicle enters the roundabout ("2" event). Prior to the inclusion of exiting vehicles, the scenario would be considered a follow-up headway observation. However, if exiting vehicles are included the two entering vehicles did not enter the same gap and therefore there is not a follow-up headway observation.

Figure 22 displays the move-up time frequency of move-up times with exiting vehicles. The move-up time threshold is 3.6 seconds which is the 95^{th} percentile move-up time when including exiting vehicles. Figure 23 displays the move-up time frequency of move-up times without exiting vehicles. The move-up time is 4.0 seconds which is the 95^{th} percentile move-up time when excluding exiting vehicles. The move-up time is smaller when exiting vehicles are included because the exiting vehicles split large gaps into more, smaller gaps; therefore, only the follow-up headway observations that were able to occur in the smaller gaps are included. In addition, the smaller gaps created by the exiting vehicles is why there are fewer observations of move-up time when exiting vehicles are included.

Table 10 lists the follow-up headway values for the queued data method and the move-up time method for the data set including exiting vehicles. Table 11 lists the follow-up headway values for the queued data method and the move-up time method for

the data set excluding exiting vehicles. The move-up time method increased the number of follow-up headway observations by 30% for the data set including exiting vehicles and 40% for the data set excluding exiting vehicles.

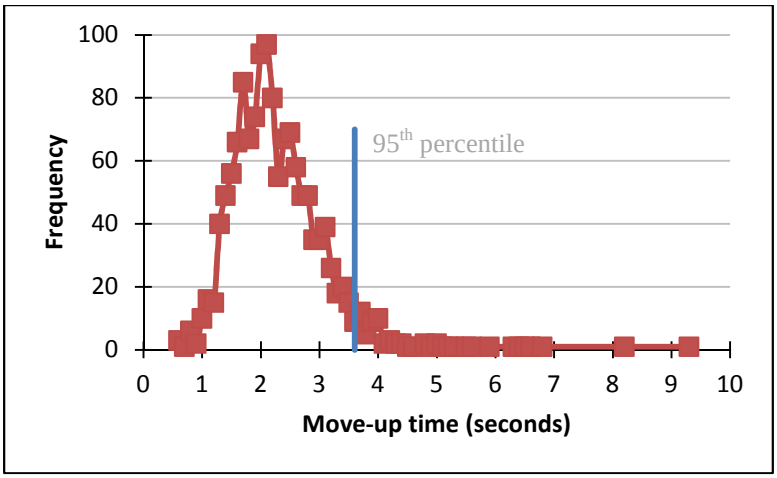


Figure 22. Move-up time frequency for queued data with exiting vehicles (n=1371)

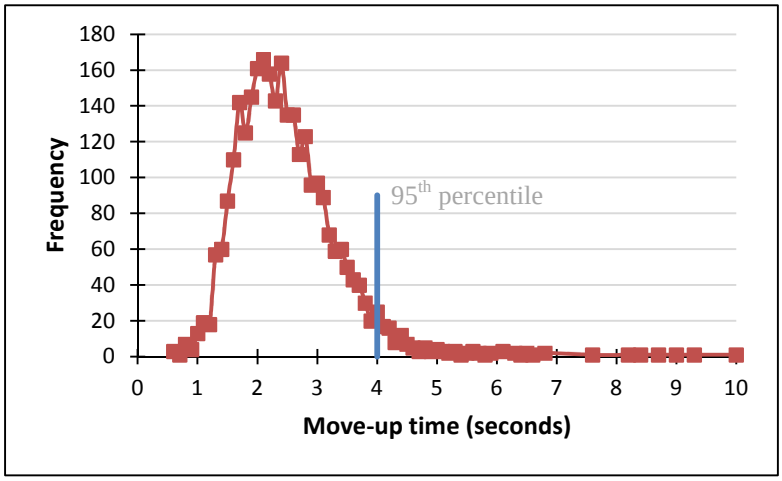


Figure 23. Move-up time frequency of queued data without exiting vehicles (n=2886)

Table 10. Follow-up headway including exiting vehicles

Site	Queued Data			Move-up Time < 3.6 sec.		
	n	t_f (s)	std. dev.	n	t_f (s)	std. dev.
ALP01-SB	1	2.624	n/a	118	2.813	0.7
COV01-SB	514	2.778	0.8	415	2.635	0.6
COV01-NB	170	2.736	0.7	241	2.775	0.7
COV01-WB	7	2.503	1.2	117	2.575	0.7
COV01-EB	1	1.129	n/a	3	2.204	0.9
COL01-SEB	5	3.271	1.1	107	2.972	0.8
COL01-SWB	12	3.119	0.7	264	2.934	0.7
DOU01-EB	0	n/a	n/a	89	2.743	0.7
DOU01-WB	11	3.167	0.7	217	2.708	0.7
DOU01-SB	0	n/a	n/a	45	2.689	1.0
EMO01-SEB	70	3.68	1.4	101	3.235	0.6
FAY01-EB	17	2.84	1.1	188	2.969	1.0
FAY01-SB	23	3.288	1.9	213	2.909	0.9
FAY01-NB	8	4.19	0.4	170	3.051	0.8
DUL01-EB	0	n/a	n/a	107	2.78	0.9
HIN01-WB	0	n/a	n/a	10	3.12	0.4
HIN01-SB	0	n/a	n/a	84	2.933	0.6
HOL01-EB	0	n/a	n/a	36	2.961	0.5
HOL01-NB	1	4.417	n/a	29	2.947	0.7
VIL01-SWB	81	2.535	0.6	571	2.593	0.6
NEW01-EB	9	4.077	2.6	120	3.037	0.8
NEW01-WB	32	2.927	0.8	252	3.113	0.9
ROS01-EB	35	2.956	0.8	191	2.696	0.7
ROS01-SWB	94	2.725	0.7	378	2.63	0.7
ROS02-EB	32	2.883	1.0	125	2.684	0.6
ROS02-SWB	248	2.926	0.8	267	2.762	0.6
STS01-WB	0	n/a	n/a	24	2.543	0.6
STS01-EB	0	n/a	n/a	33	2.321	0.9
Total	1371			4515		
Weighted Average (s)		2.871	0.836		2.788	0.714

Table 11. Follow-up headway excluding exiting vehicles

Site	Queued Data			Move-up Time < 4.0 sec.		
	n	t_f (s)	std. dev.	n	t_f (s)	std. dev.
ALP01-SB	18	4.035	1.8	248	3.412	1.1
COV01-SB	1167	3.477	1.3	1339	3.348	1.1
COV01-NB	637	3.792	1.5	1059	3.687	1.4
COV01-WB	11	3.16	1.6	169	2.966	1.4
COV01-EB	1	1.129	n/a	5	2.655	0.9
COL01-SEB	6	3.701	1.4	158	3.375	1.0
COL01-SWB	22	3.556	1.3	397	3.38	1.1
DOU01-EB	0	n/a	n/a	94	2.81	0.7
DOU01-WB	16	3.481	0.9	258	2.931	0.8
DOU01-SB	0	n/a	n/a	54	3.108	1.1
EMO01-SEB	85	3.897	1.5	133	3.512	0.9
FAY01-EB	24	3.226	1.5	259	3.259	1.3
FAY01-SB	25	3.361	1.8	244	3.078	1.0
FAY01-NB	14	4.027	0.7	248	3.414	1.1
DUL01-EB	0	n/a	n/a	146	3.088	1.0
HIN01-WB	0	n/a	n/a	18	3.635	0.9
HIN01-SB	0	n/a	n/a	120	3.317	1.0
HOL01-EB	0	n/a	n/a	51	3.107	0.6
HOL01-NB	3	3.882	0.7	42	3.137	0.7
VIL01-SWB	133	2.812	1.0	825	2.878	0.9
NEW01-EB	10	3.892	2.5	172	3.167	0.9
NEW01-WB	52	3.242	0.9	368	3.409	1.2
ROS01-EB	102	3.624	1.5	505	3.327	1.1
ROS01-SWB	132	3.19	1.5	474	2.913	1.0
ROS02-EB	92	3.747	1.7	352	3.447	1.2
ROS02-SWB	336	3.249	1.2	351	3.061	1.0
STS01-WB	0	n/a	n/a	30	2.843	0.9
STS01-EB	0	n/a	n/a	37	2.519	1.0
Total	2886			8156		
Weighted Average (s)		3.502	1.4		3.265	1.0

The follow-up headway values that will be used in this study's capacity equations are weighted average values calculated using NCHRP's move-up time method. This method was selected because there not enough follow-up headway observations from the

queued data method. Table 12 shows the average, weighted average, and median follow-up headway values for all sites. This study chose to use the weighted average follow-up headway values, 2.788 and 3.265 seconds for data sets with and without exiting vehicles respectively, from the list with all site locations.

Table 12. Follow-up headway values for all sites using NCHRP Report 572 move-up time method

	ALL 28 APPROACHES	
	With exiting	Without exiting
Average (s)	2.798	3.171
Weighted average (s)	**2.788**	**3.265**
Median (s)	2.694	3.040
n	4515	8156

4.4 Exiting Vehicle Comparison

Critical and follow-up headway values were calculated using data with and without exiting vehicle data. Figure 24 compares the critical headway values for each approach when exiting vehicles are included to the critical headway values when exiting vehicle are excluded in the data analysis. In this figure, the critical headway values being compared were calculated using NCHRP Report 572 Method 2. The sites DOU01-SB, DUL01-EB, and STS01-EB do not have critical headway data because the sites did not have the gap data necessary for calculating critical headway without exiting vehicles using Method 2.

A majority of the critical headway values for the analysis including exiting vehicles are smaller than the critical headway values excluding exiting vehicles. The smaller headway values are a result of the splitting of a single gap into smaller gaps by the exiting vehicles. Therefore, entering vehicles accept and reject smaller gaps than if

exiting vehicles were not included. This also explains why there are 36% more critical headway observations in the analyses including exiting vehicles than the analyses excluding exiting vehicles.

Follow-up headway is more influenced by the inclusion of exiting vehicles than critical headway. Figure 25 compares the follow-up headway values for each approach when exiting vehicles are included to the follow-up headway values when exiting vehicle are excluded in the data analysis. For every site, the follow-up headway value is smaller when exiting vehicles are included than when exiting vehicles are not included. The five sites with the biggest decrease in follow-up headway when exiting vehicles were included are COV01-SB, ROS02-EB, ROS01-EB, COV01-NB, and ALP01-SB. These five sites are five of the top six sites with the highest percentage of exiting vehicles at 78%, 82%, 82%, 84%, and 59% respectively. Therefore, the proportion of conflicting vehicles that are exiting vehicles does impact the follow-up headway values. Figure 26 displays the percentage of conflicting vehicles that are circulating vehicles and exiting vehicles.

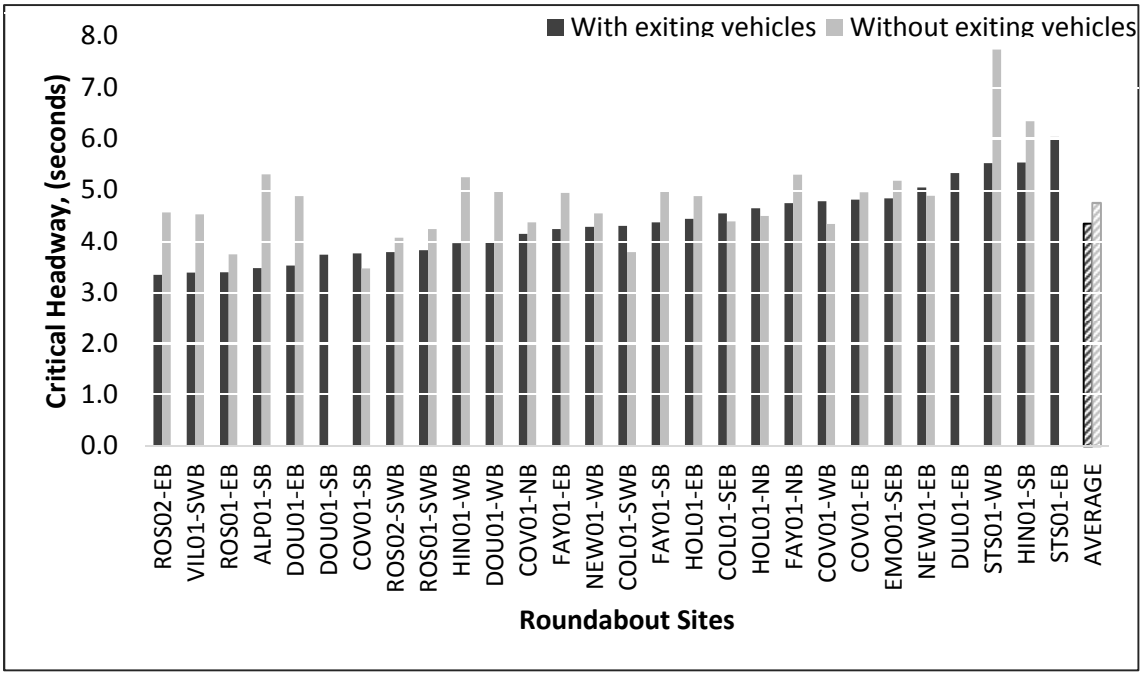


Figure 24. Comparison of critical headway values with and without exiting vehicles by approach

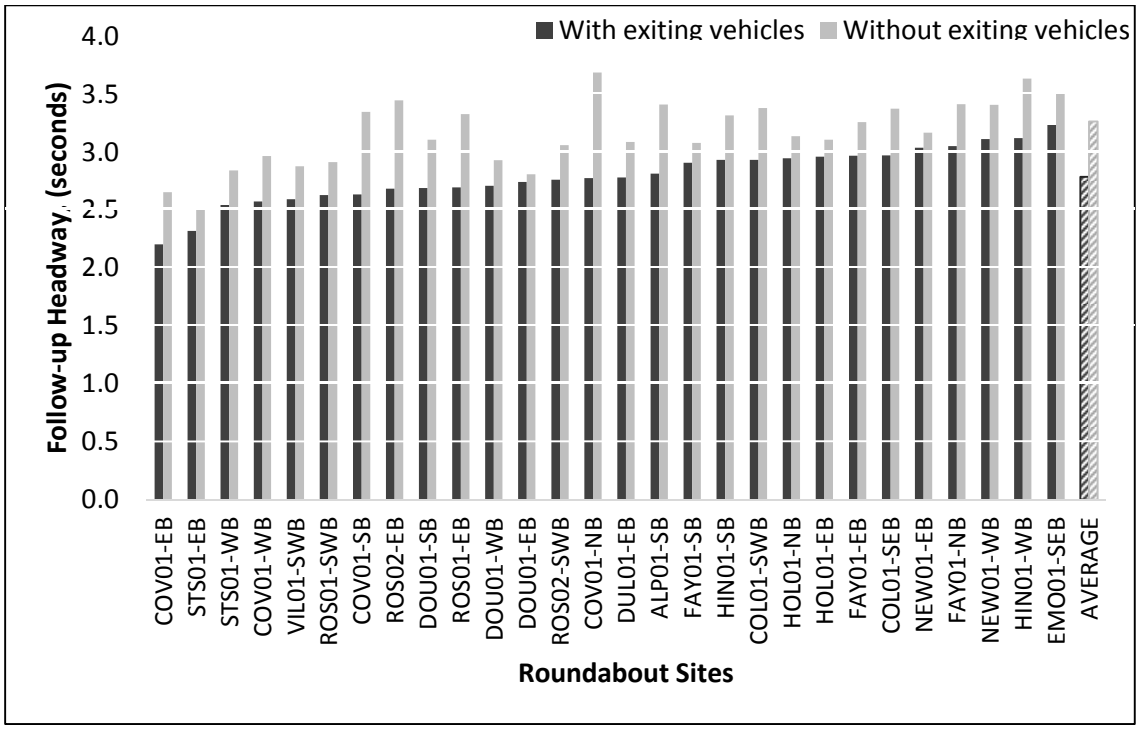


Figure 25. Comparison of follow-up headway values with and without exiting vehicles by approach

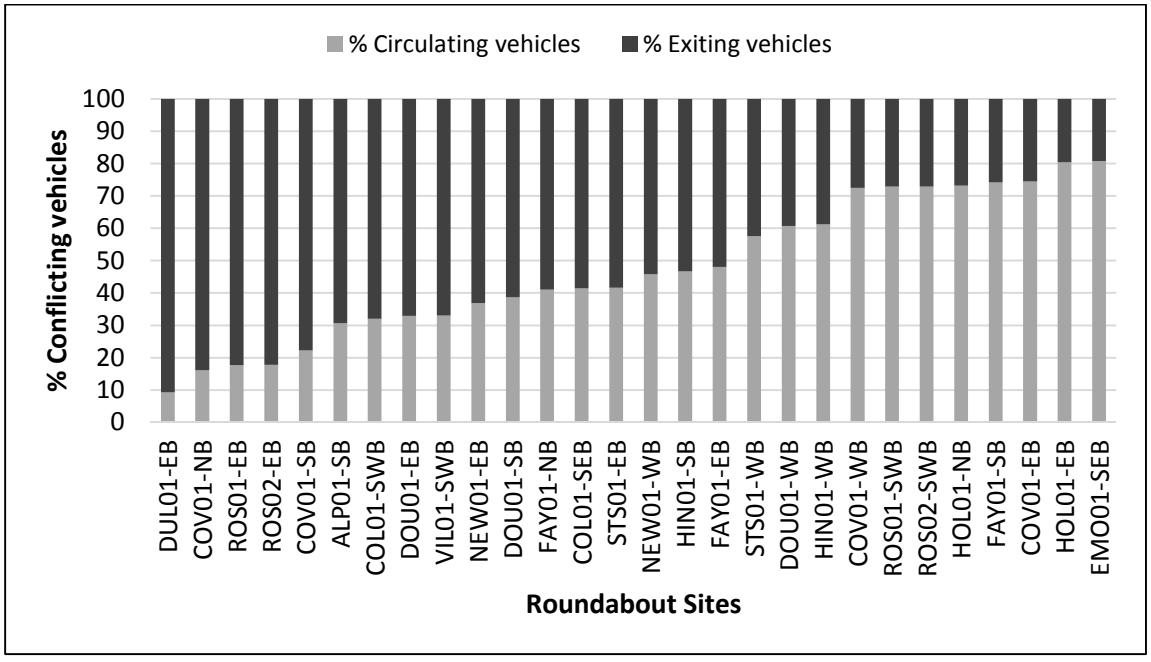


Figure 26. Percentage of conflicting vehicles that are exiting and circulating vehicles

4.5 Equation Calibration

The 2010 HCM single-lane roundabout capacity equations are calibrated based on follow-up and critical headway values. For comparison sake, this study calibrated a capacity equation for each roundabout approach based on the headway values for that approach. Figure 27 displays the calibrated roundabout capacity equations including exiting vehicles for all 28 sites. The legend to the right of the graph displays the roundabout sites in order (top to bottom) of highest to lowest entry capacity at the conflicting flow of 1500 vph. The dashed line represents the proposed GDOT calibrated model using the overall weighted average critical and follow-up headway values of 4.192 and 2.788 seconds respectively. Figure 28 displays the calibrated roundabout capacity equations excluding exiting vehicles for each of the site locations. The legend for this figure is also listed in the order of the highest to lowest entry capacity at the conflicting flow of 1500 vph. The dashed line represents the proposed GDOT calibrated model using the overall weighted average critical and follow-up headway values of 4.747 and 3.265 seconds respectively. The value 1500 vehicles per hour is arbitrary and selected because this is the last conflicting flow data point on the graph.

In order to provide a calibrated capacity equation for Georgia, the weighted average headway values were used to develop capacity equations for analysis including exiting vehicles and excluding exiting vehicles. For an analysis including exiting vehicles the critical headway is 4.192 seconds and the follow-up headway is 2.788 seconds and the calibrated equation is shown below as Equation 16. For an analysis excluding exiting vehicles the critical headway is 4.747 seconds and the follow-up headway is 3.265 seconds and the calibrated equation is shown below as Equation 17.

$$c_{e,pce} = 1256e^{(-0.0008 \times v_{c,pce})} \quad \textbf{(16)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

$$c_{e,pce} = 1101e^{(-0.0009 \times v_{c,pce})} \quad \textbf{(17)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

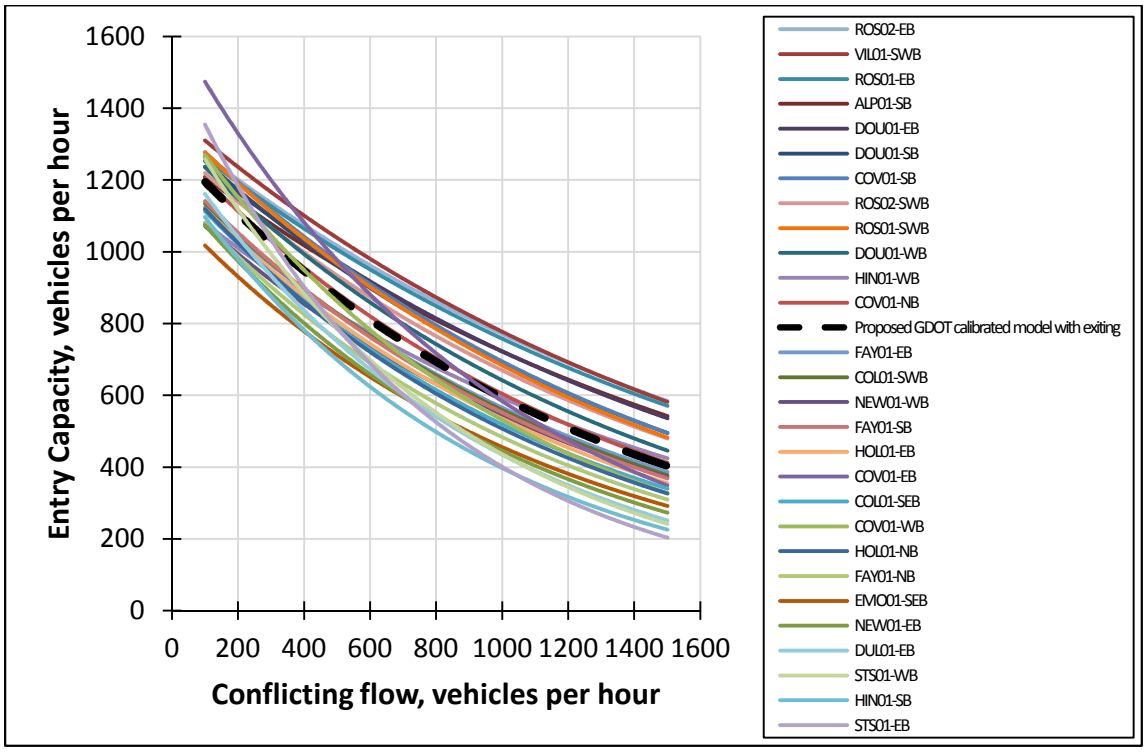


Figure 27. Calibrated single-lane roundabout capacity equations including exiting vehicles by approach

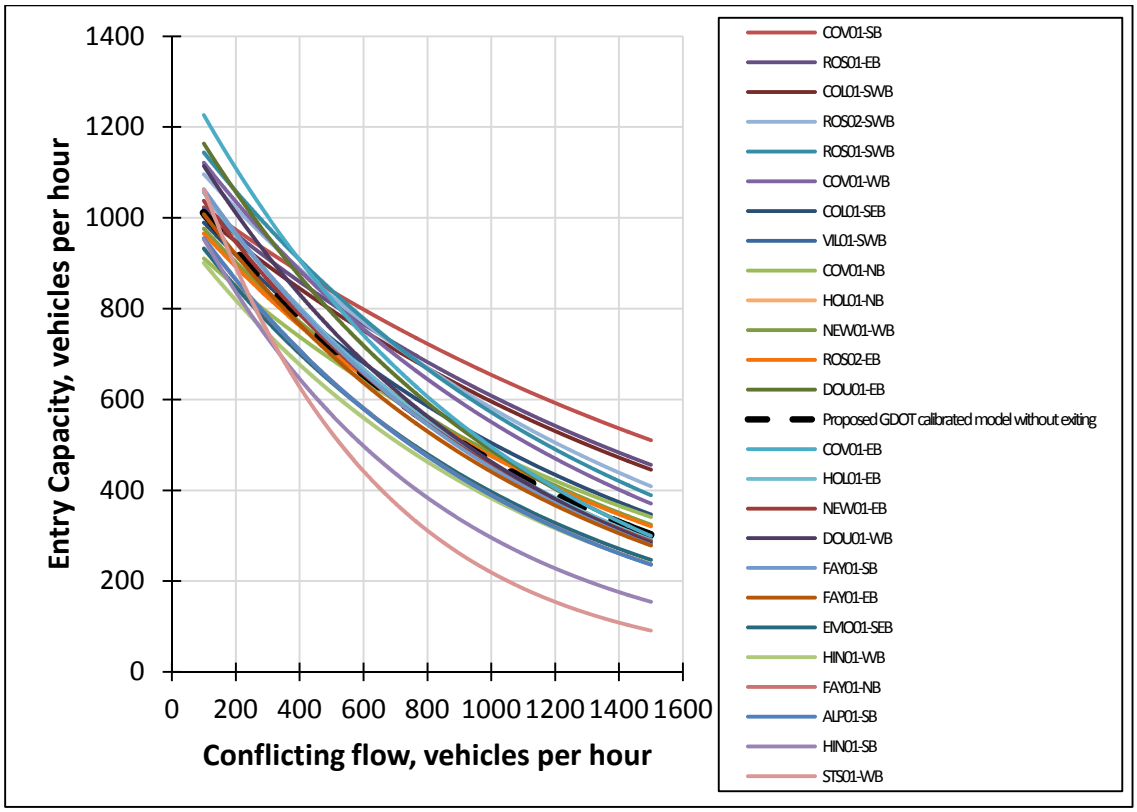


Figure 28. Calibrated single-lane roundabout capacity equations excluding exiting vehicles by approach

4.6 Comparison

A comparison of this study's equations with the current HCM 2010 capacity model is shown in Figure 29. This figure shows that the proposed model with exiting vehicles predicts higher capacity than the proposed model without exiting vehicles. However, this statement is not always true and is dependent upon the percentage of conflicting vehicles that are exiting vehicles. For example, as shown in Table 13, 78% of COV01-SB's conflicting vehicles are exiting vehicles. The capacity prediction for COV01-SB without exiting vehicles is 949 vph. When exiting vehicles are included in the capacity model the capacity prediction decreases to 696 vph. However, the capacity prediction for HOL01-NB increases when exiting vehicles are included because only 27% of the conflicting volume is exiting vehicles. Therefore, the impact of including exiting vehicles is dependent upon the percentage of conflicting vehicles that are exiting

vehicles. Also shown in Figure 30, the proposed model without exiting vehicles predicts a higher capacity than the HCM 2010 model except for at very low conflicting volumes which also excludes exiting vehicles. In addition, the proposed model is not adjusted for passenger car equivalents. Once this adjustment is incorporated it is likely the Georgia calibrated equations will show slightly higher capacities.

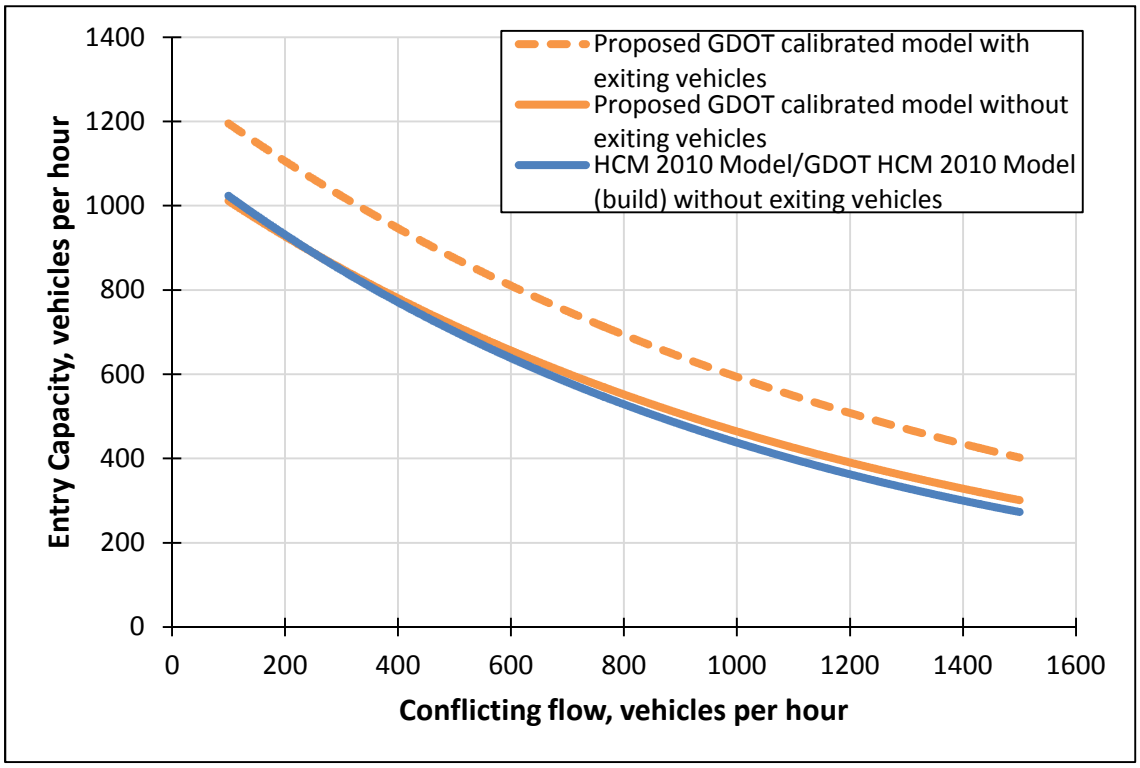


Figure 29. Existing HCM 2010 model and proposed calibrated capacity equations

Table 13. Comparison of capacities for COV01-SB and HOL01-NB

Site		COV01-SB	HOL01-NB
Conflicting Vehicles	Circulating Vehicles (vph)	165	592
	Exiting Vehicles (vph)	573	217
	Total (vph	738	809
Percent conflicting vehicles that are exiting vehicles (%)		78	27
Capacity without exiting vehicles (vph)		949	646
Capacity with exiting vehicles (vph)		696	658

Table 14 provides the follow-up and critical headway values for the HCM 2010 capacity model, the calibrated models from Bend, Oregon, Caltrans, and Wisconsin, and the proposed GDOT models. Figure 30 displays curves for all of the capacity equation models listed in Table 14. Except for the Bend, Oregon data, at the higher conflicting flows all the capacity models including exiting vehicles are shifted up and to the right relative to the models without exiting vehicles. Recall this does not necessarily imply higher capacities as exiting vehicles increases the total conflicting vehicle. Interestingly the Bend, Oregon headway values and the proposed GDOT model with exiting vehicles values curve are very similar.. The Bend, Oregon study did not include exiting drivers; therefore, the fact that the headways are so similar yet one model includes exiting vehicles and the other does not indicates that the Bend, Oregon drivers are much more aggressive than drivers in Georgia. The aggressive behavior could come from driver's familiarity with roundabouts. There are 25 roundabouts in the City of Bend alone whereas there are approximately 100 in the entire state of Georgia [24]. Therefore, drivers in Bend, Oregon have a high concentration of roundabouts and are probably very familiar with driving in roundabouts and feel comfortable accepting smaller gaps than drivers in Georgia. Although additional study is necessary to confirm this hypothesis.

Table 14. Follow-up and critical headway values for current and proposed models

Model	Follow-up Headway (seconds)	Critical Headway (seconds)	Exiting vehicles considered?
Proposed GDOT calibrated model with exiting vehicles	2.788	4.192	Yes
Proposed GDOT calibrated model without exiting vehicles	3.265	4.747	No
Bend, Oregon/ GDOT Calibrated Model (future)	2.7	4.1	No
Caltrans	2.5	4.8	No
HCM 2010 Model/GDOT HCM 2010 Model (build)	3.2	5.0	No
Wisconsin			
Canal Street at 25th St.	2.6	5.5	No
	2.3	4.6	Yes
Sth 78 at CTH ID	3.8	4.8	No
	3.1	3.8	Yes

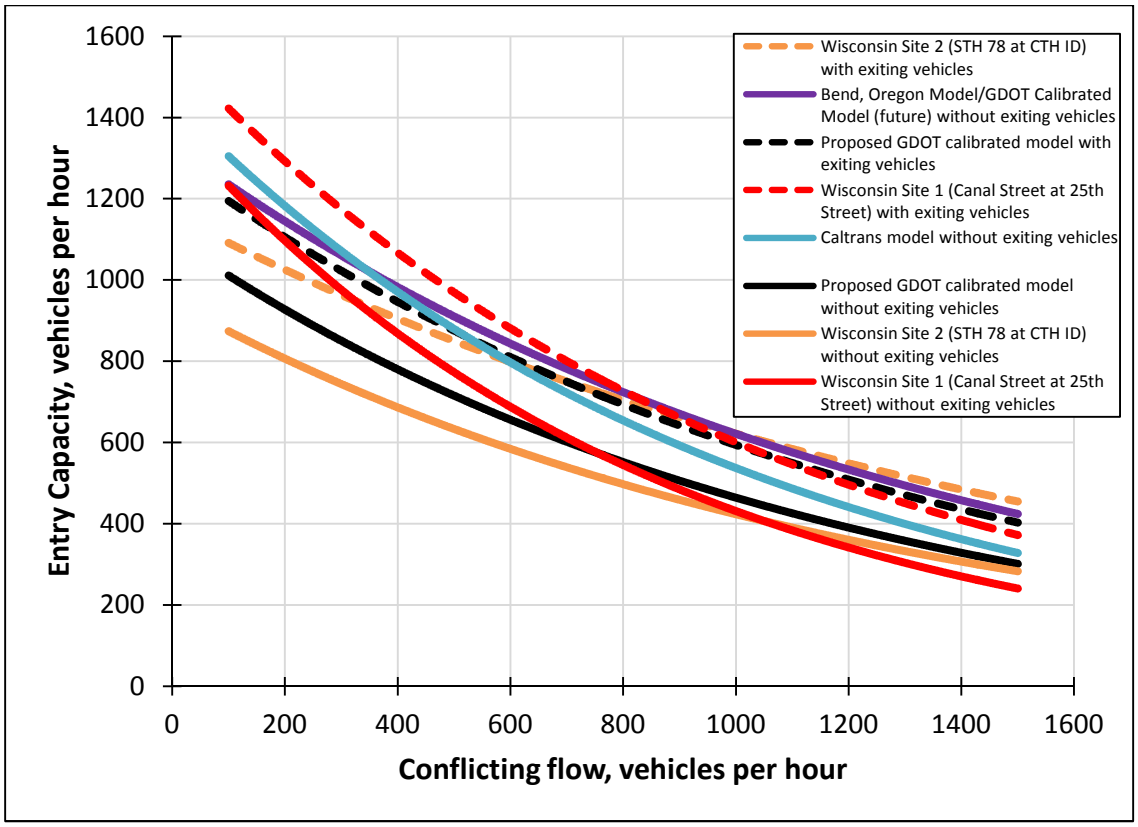


Figure 30. Comparison of capacity equation models

4.7 Modified List

Some of the data collection sites did not have consistent modern roundabout geometry or the site had unique features. For example, the EMO0-SEB roundabout site shown in Figure 31 has a large slope which makes it a unique roundabout site. Therefore, the research team wanted to determine weighted average headway values for sites with the most consistent modern-roundabout features. The sites with only modern-roundabout features were compiled and put into a list called “Modified List”.

Figure 31. Large slope at roundabout in Atlanta, Georgia (Source: Google Earth™, accessed October 22, 2013)

Once headway values were established, the team wanted to examine if the Modified List would yield different headway values than the list including all the sites. Table 15 displays the data collection sites. The shaded rows indicate roundabouts that have the modern roundabout geometry. The rows that are not shaded indicate locations that either do not have a modern roundabout geometry or have unique features. The Modified list includes the six roundabout sites (13 approaches) shaded in Table 15.

Table 15. Roundabout data collection sites

Site	City	Lane Configuration			Collection Date	Approach	Time Duration (hr)	Site ID.
		Circulating Lanes	Legs	Slip Lanes				
Douglas Rd./Southlake Dr./Leeward Walk Cir.	Alpharetta	1	4	0	11/13/2012	SB	1:57	ALP01-SB
Turner Lake Rd. SW/Clark St. SW	Covington	1	4	0	3/1/2012	SB	2:33	COV01-SB
						NB	2:24	COV01-NB
					5/24/2012	WB	2:25	COV01-WB
						EB	2:11	COV01-EB
Warm Springs Rd./Blackmon Rd	Columbus	1	4	0	11/2/2012	SEB	1:39	COL01-SEB
						SWB	2:07	COL01-SWB
SR 166 (Duncan Memorial Hwy)/SR 5 (Bill Arp Rd.)	Douglasville	1	4	2	5/14/2012	EB	2:17	DOU01-EB
						WB	2:10	DOU01-WB
					11/1/2012	SB	1:27	DOU01-SB
N. Decatur Rd./Oxford Rd NE.	Atlanta	1	5	1	10/19/2012	SEB	1:49	EMO01-SEB
Grady Ave./Beauregard Blvd.	Fayetteville	1	4	1	4/11/2012	EB	2:04	FAY01-EB
						SB	2:02	FAY01-SB
					10/23/2012	NB	2:19	FAY01-NB
McClure Bridge Rd./W. Lawrenceville St./Irvindale Rd. NW	Duluth	1	3	0	6/1/2012	EB	1:49	DUL01-EB
N. Main St./Memorial Dr.	Hinesville	1	4	0	7/27/2012	WB	1:11	HIN01-WB
						SB	1:39	HIN01-SB
Holly Springs Rd./Davis Rd.	Marietta	1	4	0	10/11/2012	EB	1:58	HOL01-EB
						NB	1:52	HOL01-NB
Villa Rica/Sandtown	Marietta	1	4	0	3/27/2012	SWB	1:52	VIL01-SWB
E. Broad St./Greison Tr./E. Newnan Rd.	Newnan	1	4	0	10/25/2012	EB	1:55	NEW01-EB
						WB	1:52	NEW01-WB
Grimes Bridge Rd./Norcross St./Warsaw Rd./Melody Ln.	Roswell	1	5	2	5/15/2012	EB	2:06	ROS01-EB
						SWB	2:06	ROS01-SWB
					10/26/2012	EB	2:00	ROS02-EB
						SWB	2:00	ROS02-SWB
Lawrence Rd./Frederica Rd.	St. Simons	1	3	0	7/28/2012	WB	2:52	STS01-WB
						EB	2:08	STS01-EB
						Total	**56:44:00**	

Modern roundabout geometry

Table 16. Critical headway values for modified site list using NCHRP Report 572 critical headway Method 2

	ALL 28 APPROACHES		MODIFIED LIST (13 APPROACHES)	
	With exiting	Without exiting	With exiting	Without exiting
Average (s)	4.344	4.445	4.312	4.686
Weighted average (s)	4.192	4.747	4.262	4.738
Median (s)	4.230	4.938	4.276	4.876
Number of observations	3739	1344	2100	758

Table 17. Follow-up headway values for modified site list using NCHRP Report 572 move-up time method

	ALL 28 APPROACHES		MODIFIED LIST (13 APPROACHES)	
	With exiting	Without exiting	With exiting	Without exiting
Average (s)	2.798	3.171	2.814	3.194
Weighted average (s)	2.788	3.265	2.798	3.312
Median (s)	2.694	3.040	2.686	3.084
Number of observations	4515	8156	2473	5029

Figure 2733 displays the calibrated roundabout capacity equations including exiting vehicles for the sites on the Modified List. The legend to the right of the graph displays the roundabout sites in order (top to bottom) of highest to lowest entry capacity at the conflicting flow of 1500 vph. The dashed line represents the proposed GDOT calibrated model using the overall weighted average critical and follow-up headway values of 4.262 and 2.798 seconds respectively. Figure 28 displays the calibrated roundabout capacity equations excluding exiting vehicles for each of the site locations. The legend for this figure is also listed in the order of the highest to lowest entry capacity at the conflicting flow of 1500 vph. The dashed line represents the proposed GDOT calibrated model using the overall weighted average critical and follow-up headway values of 4.738 and 3.312 seconds respectively.

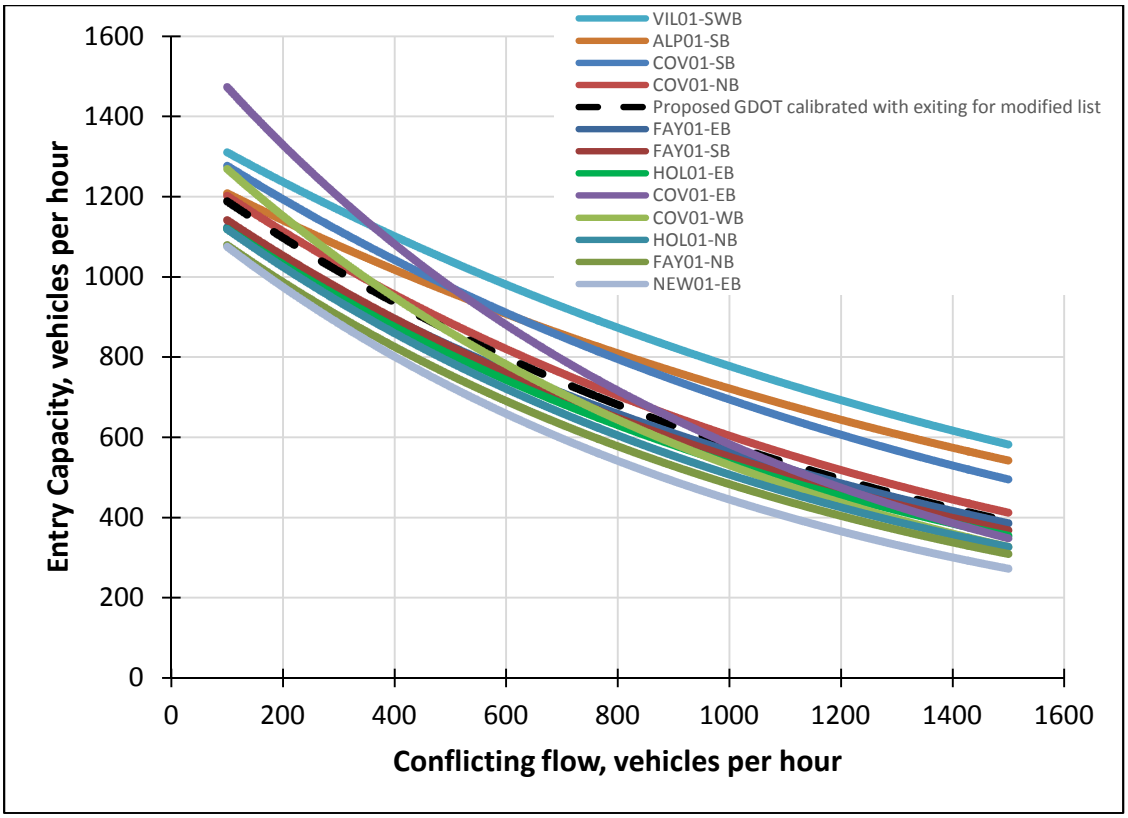


Figure 31. Calibrated single-lane roundabout capacity equations including exiting vehicles for modified list

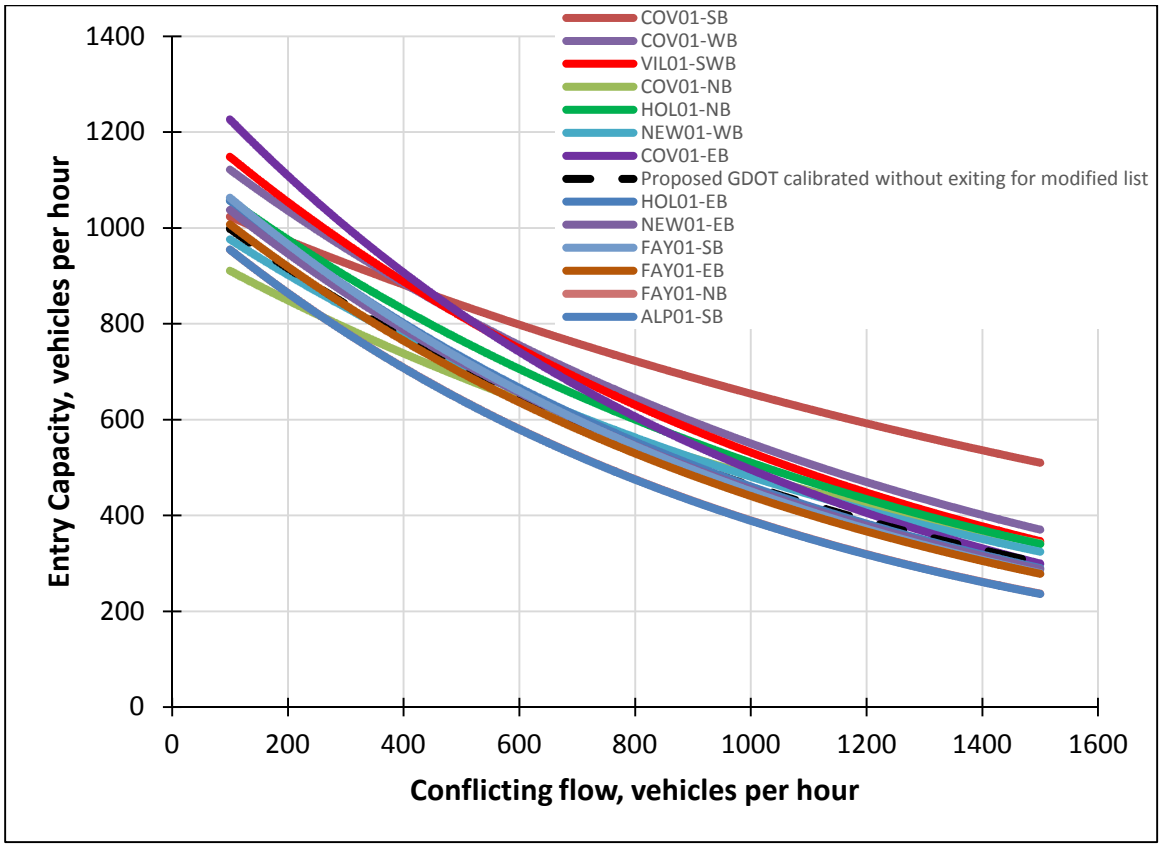


Figure 32. Calibrated single-lane roundabout capacity equations excluding exiting vehicles for modified list

The weighted average headway values were used to develop capacity equations for analysis including exiting vehicles and excluding exiting vehicles for the Modified List. The calibrated equation for the Modified List including exiting vehicles is shown below as Equation 17. The calibrated equation for the Modified List excluding exiting vehicles is shown below as Equation 18.

$$c_{e,pce} = 1287e^{(-0.0008 \times v_{c,pce})} \quad \textbf{(17)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

$$c_{e,pce} = 1087e^{(-0.0009 \times v_{c,pce})} \quad \textbf{(18)}$$

Where:

$c_{e,pce}$ = capacity of the approach lane under consideration in passenger car equivalents, veh/h

$v_{c,pce}$ = conflicting flow in passenger car equivalents, veh/h

Table 16 shows there is an insignificant difference between the critical headway values from the list with all site locations and the modified list. Table 17 shows there is an insignificant difference between the follow-up headway values from the list with all site locations and the modified list. There is less than a 0.1 seconds difference between the headway values. Figure 33 and Figure 34 further show the limited difference with the modified list. These results suggest that difference in geometry between the modified list roundabouts and the other roundabouts was not sufficient to affect the operations of the roundabout. Thus, it is recommended to use the calibrated equations based on all 28 roundabout approaches.

CHAPTER 5: CONCLUSIONS

GDOT developed a Roundabout Analysis Tool in order to predict the operations of future roundabouts. The tool uses two different single-lane roundabout capacity models. The first model is the default single-lane roundabout capacity equation found in the 2010 Highway Capacity Manual (HCM). The second model is the 2010 HCM single-lane roundabout capacity equation calibrated with follow-up and critical headway values from California and Bend, Oregon. The purpose of this study was to measure follow-up and critical headways at Georgia roundabouts in order to calibrate the 2010 HCM capacity equations to yield improved capacity predictions.

This study closely followed the methodology of the NCHRP Report 572. The NCHRP Report 572 presents several methods for calculating both follow-up and critical headway. Follow-up headway was calculated using the queued data method and the move-up time method. Critical headway was calculated using Method 1, 2, and 3 presented in the NCHRP Report 572. All methods were used, but like the NCHRP Report 572, the final model utilizes the critical headway Method 2 and the follow-up headway move-up time method. Lastly, this study analyzed the impact of including exiting vehicles in the roundabout analysis by calculating follow-up and critical headway with exiting vehicle data and without exiting vehicle data.

The research team filmed 28 approaches at thirteen Georgia roundabouts for a total of 56.5 hours. The critical and follow-up headway for an analysis including exiting vehicles is 4.192 seconds and 2.788 seconds respectively. The critical and follow-up headway for an analysis excluding exiting vehicles is 4.747 seconds and 3.265 seconds respectively. The HCM 2010 default values for critical and follow-up headway are 3.2 and 5.0 seconds respectively. This study's calibrated model excluding exiting vehicles predicts higher capacity than the 2010 HCM model except at conflicting volumes of 300

vehicles per hour or less. However, the proposed model is not adjusted for passenger car equivalents. Once this adjustment is incorporated it is likely the Georgia calibrated equations will show slightly higher capacities.

Also, this study found that exiting vehicles do influence the capacity predictions. The study found that the percentage of conflicting vehicles that were exiting vehicles influenced the change in the headway values. At sites with a large percentage of exiting vehicles, the follow-up headway values had the largest decrease when exiting vehicles were included in the analysis. Therefore, this study suggests that not only do exiting vehicles impact the capacity but the proportion of conflicting vehicles that are exiting vehicles is influential as well.

Lastly, this study also calculated the follow-up and critical headway values for sites with consistent modern roundabout features. Six of the thirteen roundabouts this study collected data were considered roundabouts. These six roundabouts made up a "modified list". The critical and follow-up headway values for the modified list excluding exiting vehicles are 4.738 and 3.312 seconds respectively. The critical and follow-up headway values for the proposed model utilizing all the sites and excluding exiting vehicles are 4.747 and 3.265 seconds respectively. There is less than a 0.1 seconds difference between the headway values. These results suggest that the geometric differences between the modified list and remaining roundabouts do not affect the operations of the roundabout. However, this finding should not be interpreted as modern roundabout geometry is not effective, only that the roundabouts in this study were not sufficiently different to impact capacity. Also, this analysis does not consider the potential safety benefits of the modern roundabout geometry as this was outside the scope of this project.

5.1 Limitations

One limitation of the study is the age of the roundabouts that were used in this study. A majority of the roundabouts were built in the last five years which would cause variable data because drivers are still adjusting to driving in roundabouts. Also, with the exception of the Covington and Roswell roundabouts no other sites had consistent queuing. Therefore, only data from Covington and Roswell was captured under consistently capacity constrained conditions. This study recommends another study be performed in five to ten years to mitigate new driver variability and potentially observe more queuing on the approaches.

As mentioned in the QA/QC section of this report the NCHRP Report 572 collected all keystrokes in one pass through the video. This study chose not follow the NCHRP method because preliminary testing found it very difficult to accurately capture all keystrokes in real time in one pass through the video. Rather this study elected to collect the keystrokes over three passes through the same video. However, review of the data has shown that as all timestamps are not collected in one pass through the video it is possible that when the keystrokes are merged and sorted the order of the keystrokes could be different than the actual order of events, based on differences in the URAs reaction time to the different events and selected keystrokes. Therefore, when the critical and follow-up headway values are being compared between the URAs, only observations with the same order are compared. This study believes that this study's methodology, despite allowing a few instances of inconsistent order of events, produces less error and inconsistency than if all keystrokes were to be collected at once in real-time. However, future efforts should consider alternative data collection methods, such as all keystrokes are collected in one pass through a video shown at half speed.

APPENDIX A: FOLLOW-UP AND CRITICAL HEADWAY EXAMPLES

A.1 Follow-up Headway Example

"The follow-up headway, t_f, is defined as the headway maintained by two consecutive entering vehicles using the same gap in the conflicting stream" – NCHRP Report 572

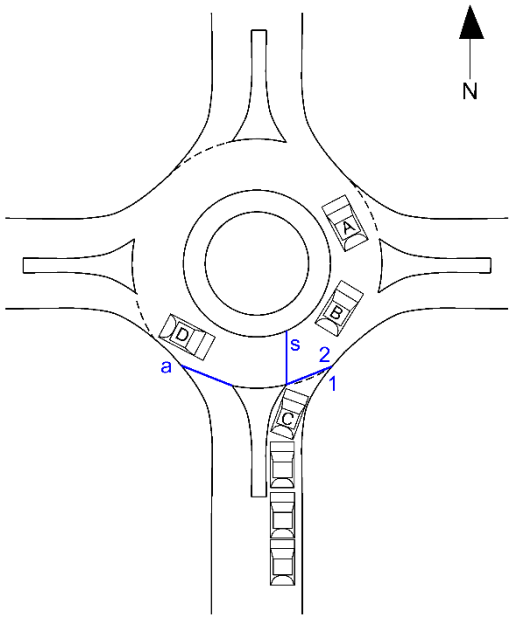


Figure 33. Schematic for follow-up headway example

ASSUMPTIONS:

1. Constant queuing is present on the south leg of the roundabout
2. Vehicle A is circulating in the roundabout and crosses line "s" at t = 0 sec.
3. Vehicle B enters the roundabout and crosses line "2" at t = 2 sec.
4. Vehicle C enters the roundabout and crosses line "2" at t = 4 sec.
5. Vehicle D is circulating in the roundabout and crosses line "s" at t = 7 sec.

Sample calculation for the follow-up headway between Vehicles B and C:

$$t_f = C_2 - B_2$$
$$t_f = 4\ sec. - 2\ sec.$$
$$t_f = 2\ sec.$$

Where:

$t_f = follow - up\ headway, sec.$

$C_2 = timestamp\ when\ Vehicle\ C\ crosses\ line$ "2"

$B_2 = timestamp\ when\ Vehicle\ B\ crosses\ line$ "2"

A.2 Critical Headway NCHRP Method 1 Example

Method 1 is the inclusion of all observations of gap acceptance, including rejected lags

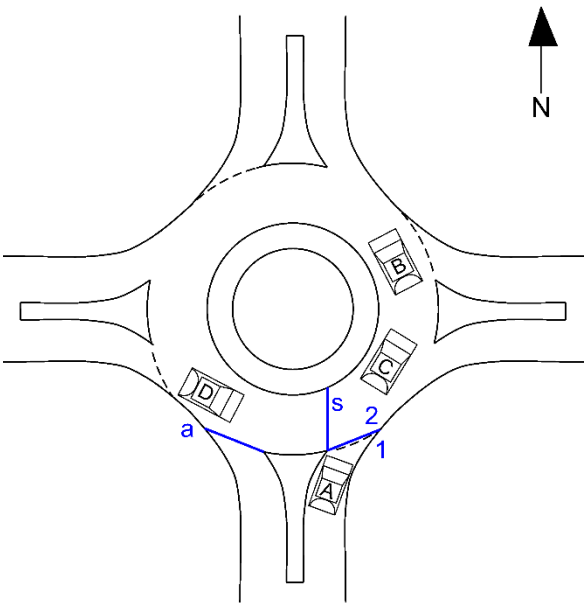


Figure 34. Schematic for critical headway NCHRP Method 1 example

ASSUMPTIONS:

1. Vehicle A arrives at the roundabout and stops at line "1" at t = 0 sec.
2. Vehicle B is circulating the roundabout and crosses line "s" at t = 1 sec.
3. Vehicle C is circulating in the roundabout and crosses line "s" at t = 3 sec.
4. Vehicle A enters the roundabout and crosses line "2" at t = 6 sec.
5. Vehicle D is circulating in the roundabout and crosses line "s" at t = 8 sec.

Sample calculations for the accepted and rejected gaps and lags:

1. Rejected lag between Vehicle A and Vehicle B

$$lag = B_s - A_1$$
$$lag = 1\ sec. - 0\ sec.$$
$$lag = 1\ seconds$$

Where:
$B_S = timestamp\ when\ Vehicle\ B\ crosses\ line$ "s"
$A_1 = timestamp\ when\ Vehicle\ A\ arrives\ at\ line$ "1"

2. Rejected gap between Vehicle B and Vehicle C

$$gap = C_s - B_s$$
$$gap = 3\ sec. - 1\ sec.$$
$$gap = 2\ seconds$$

Where:
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line$ "s"
$B_S = timestamp\ when\ Vehicle\ B\ crosses\ line$ "s"

3. Accepted gap between Vehicle C and Vehicle D

$$gap = D_s - C_s$$
$$gap = 8\ sec. - 3\ sec.$$
$$gap = 5\ seconds$$

Where:
$D_S = timestamp\ when\ Vehicle\ D\ crosses\ line$ "s"
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line$ "s"

A.3 Critical Headway NCHRP Method 2 Example

Method 2 is the "inclusion of only observations that contain a rejected gap" – NCHRP Report 572

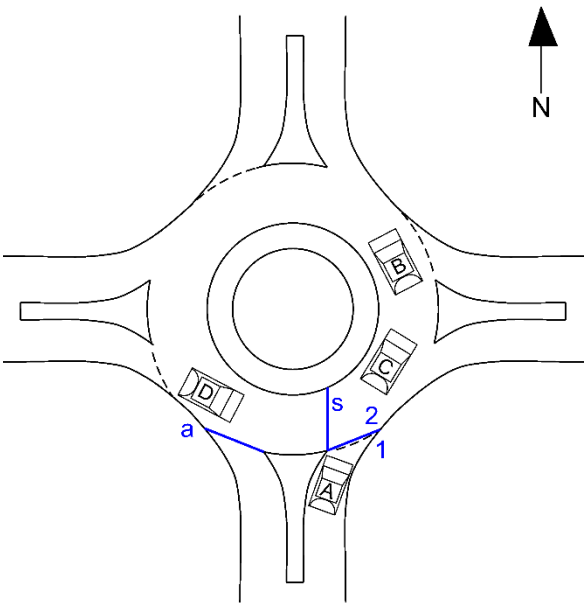


Figure 35. Schematic for critical headway NCHRP Method 2 example

ASSUMPTIONS:

1. Vehicle A arrives at the roundabout and stops at line "1" at t = 0 sec.
2. Vehicle B is circulating the roundabout and crosses line "s" at t = 1 sec.
3. Vehicle C is circulating in the roundabout and crosses line "s" at t = 3 sec.
4. Vehicle A enters the roundabout and crosses line "2" at t = 6 sec.
5. Vehicle D is circulating in the roundabout and crosses line "s" at t = 8 sec.

Sample calculations for the accepted and rejected gaps:

1. Rejected gap between Vehicle B and Vehicle C

$gap = C_s - B_s$
$gap = 3\ sec. - 1\ sec.$
$gap = 2\ seconds$

Where:
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line\ "s"$
$B_S = timestamp\ when\ Vehicle\ B\ crosses\ line\ "s"$

2. Accepted gap between Vehicle C and Vehicle D

$gap = D_s - C_s$
$gap = 8\ sec. - 3\ sec.$
$gap = 5\ seconds$

Where:
$D_S = timestamp\ when\ Vehicle\ D\ crosses\ line\ "s"$
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line\ "s"$

A.4 Critical Headway NCHRP Method 3 Example

Method 3 is the "inclusion of only observations where queuing was observed during the entire minute and the driver rejected a gap." – NCHRP Report 572

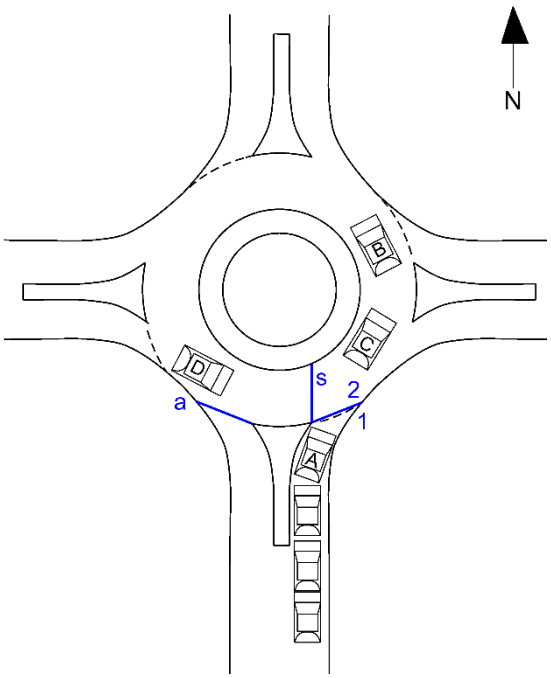


Figure 36. Schematic for critical headway NCHRP Method 3 example

ASSUMPTIONS:

1. Constant queuing is present on the south leg of the roundabout
2. Vehicle A arrives at the roundabout and stops at line "1" at t = 0 sec.
3. Vehicle B is circulating the roundabout and crosses line "s" at t = 1 sec.
4. Vehicle C is circulating in the roundabout and crosses line "s" at t = 3 sec.
5. Vehicle A enters the roundabout and crosses line "2" at t = 6 sec.
6. Vehicle D is circulating in the roundabout and crosses line "s" at t = 8 sec.

Sample calculations for the accepted and rejected gaps:

1. Rejected gap between Vehicle B and Vehicle C

$gap = C_s - B_s$
$gap = 3\ sec. - 1\ sec.$
$gap = 2\ seconds$

Where:
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line\ "s"$
$B_S = timestamp\ when\ Vehicle\ B\ crosses\ line\ "s"$

2. Accepted gap between Vehicle C and Vehicle D

$gap = D_s - C_s$
$gap = 8\ sec. - 3\ sec.$
$gap = 5\ seconds$

Where:
$D_S = timestamp\ when\ Vehicle\ D\ crosses\ line\ "s"$
$C_S = timestamp\ when\ Vehicle\ C\ crosses\ line\ "s"$

APPENDIX B: PROJECTED TRAVEL TIME EXAMPLE

This example uses Wisconsin's projected travel time method to account for exiting vehicles in the gap/lag measurement.

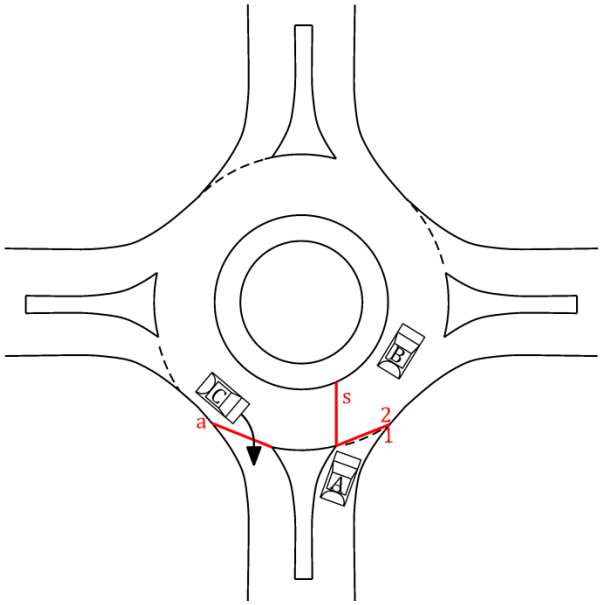


Figure 37. Schematic for projected travel time example

ASSUMPTIONS:

1. Projected travel time, Δt = 2 sec.
2. Vehicle A arrives at the roundabout and stops at line "1" at t = 0 sec.
3. Vehicle B is circulating the roundabout and crosses line "s" at t = 1 sec.
4. Vehicle C is exiting the roundabout and crosses line "a" at t = 5 sec.
5. Vehicle A enters the roundabout and crosses line "2" at t = 6 sec.

Sample calculations for the accepted and rejected gaps/lags:

1. Rejected lag between Vehicle A and Vehicle B

$$lag = T_2 - T_1 + \Delta t$$
$$lag = 1\ sec. - 0\ sec. + 0\ sec.$$
$$lag = 1\ seconds$$

Where:
$T_1 = timestamp\ when\ Vehicle\ A\ arrives\ at\ line$ "1"
$T_2 = timestamp\ when\ Vehicle\ B\ crosses\ line$ "s"

2. Rejected gap between Vehicle B and Vehicle C

$$gap = T_2 - T_1 + \Delta t$$
$$gap = 5\ sec. - 1\ sec. + 2\ sec.$$
$$gap = 6\ seconds$$

Where:
$T_1 = timestamp\ when\ Vehicle\ B\ crosses\ line$ "s"
$T_2 = timestamp\ when\ Vehicle\ C\ crosses\ line$ "a"

APPENDIX C: ROUNDABOUT DATA COLLECTION INSTRUCTIONS

C.1 Overview

1. Click on the “JavaProgram_Barry.bat” file.

Located here: Y:\common\GDOT_Roundabouts\Roundabout_Program

2. The program will open an explorer window, navigate to the video for which timestamps will be collected and open the video.
3. Enter your name in the input pop-up window and press ok.
4. The video will open up in the program and two csv files will be created in the same location as the video. The names of the csv files will be videoname.avi_param and videoname.avi_data. The program will write the timestamps into the .avi_data file as they are collected.
5. When the video opens up in the program, it should be at the beginning. There should be lines on the video corresponding to three distinct events. If there are no lines on the video, then it is the wrong video.
6. Each video will need to be watched **three times.**
7. Press play and begin collecting timestamps.
8. The cursor must be flashing in the first box on the bottom of the program window. If the cursor is not in that box, then the program will not collect timestamps.

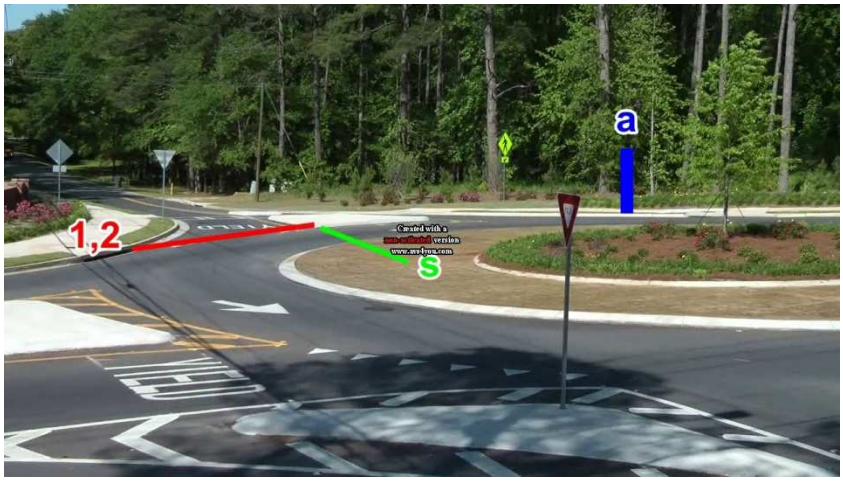


Figure 38. Interface of program

C.2 Keystrokes 1 &2

9. For the first review of the video, timestamps corresponding to the arriving and entering event should be collected.
10. The event corresponding to the arrival and entry of a vehicle on the approach of interest is denoted by the red line. The numbers 1 and 2 are shown to the left of this line to remind the collector which keys are to be pressed.
11. Check and make sure that the num lock is on. Timestamps 1 and 2 must be collected using the number pad.
12. “1” is the arrival timestamp. Press “1” when a vehicle arrives on the approach. If the car does not stop then “1” should be pressed when the front of the vehicle reaches the red line. If the vehicle stops then “1” should be pressed when the vehicle stops even if it stops before the red line. Similarly, if the arriving vehicle slows significantly due to a conflict with a circulating vehicle, “1” should be pressed when the vehicle slows its speed significantly.

13. “2” is the departing timestamp. “2” should always be pressed when the vehicle enters the roundabout. When the front of the vehicle crosses the red line “2” should be pressed regardless of where the “1” (arrival) timestamp was collected.
14. When the video ends, close the program. Navigate to the csv files and add “12_” to the beginning of the file name for both of the csv files.
15. Move the csv files into the folder named “Excel Files” that is in the same location as the video file.

C.3 Keystrokes a & s

16. For the second review of the video timestamps “a” and “s” should be collected.
17. “a” corresponds to the timestamp for exiting vehicles. The “a” key should be pressed when the front of an exiting vehicle reaches the vertical blue line on the screen.
18. “s” corresponds to the circulating vehicle timestamp. The “s” key should be pressed when the front of a circulating vehicle reaches the green line.
19. When the video ends, close the program. Navigate to the csv files and add “as_” to the beginning of the file name for both of the csv files.
20. Move the csv files into the folder named “Excel Files” that is in the same location as the video file.

C.4 Keystrokes x & z

21. Keystrokes “x” and “z” correspond to queuing data on the approach.
22. There must be at least two vehicles on the approach for a queue to exist.
23. A queue is defined to exist when a vehicle’s speed is determined by the vehicle in front of it. In other words if a vehicle is experiencing delay at the roundabout due

to the vehicle(s) in front of it on the approach, then these vehicles are considered to be queued.

24. “x” should be pressed when queuing begins on the approach. “x” should be pressed at the beginning of the queued conditions even if the queue is only two vehicles long.
25. “z” should be pressed right after the last vehicle in the queue departs the approach.
26. When the video ends, close the program. Navigate to the csv files and add “xz_” to the beginning of the file name for both of the csv files.
27. Move the csv files into the folder named “Excel Files” that is in the same location as the video file.

C.5 Data Collection Errors

1. If an error is made in the data collection, enter keystroke “q”. Continue data collection until you are finished. After you have renamed the files, open the excel file. Delete the rows with mistake keystroke and the keystroke indicator.

APPENDIX D: METHODOLOGY EXAMPLE

D.1 Raw Data

Table 18. Raw Data: Keystrokes "1" and "2"

Time Stamp	Direction
802.581	1
806.3734	2
810.1065	1
810.8215	2
813.798	1
814.3255	2
817.5901	1
818.0061	2
821.2535	1
821.7334	2
823.9101	1
824.4209	2
829.1255	1
829.8586	2
832.6738	1
838.4495	2
842.0974	1
842.6419	2
846.5617	1
850.4976	2
852.4817	1
852.8655	2
856.5944	1
857.2497	2
858.9943	1
859.5851	2
862.6266	1
863.1863	2
865.4732	1
867.9543	2
869.6048	1
870.1773	2
876.6264	1
885.2598	2
891.1484	1
896.172	2
914.9097	1
917.5037	2
926.4308	1
930.9109	2
935.150	1
936.031	2
936.690	1
937.942	2
938.834	1
939.610	2
943.358	1

Table 19. Raw Data: Keystroke "s"

Time Stamp	Direction
803.5465	s
825.947	s
827.9464	s
832.5869	s
835.6264	s
840.6183	s
843.6749	s
845.579	s
848.6984	s
855.3058	s
865.1937	s
873.87	s
879.1656	s
883.0394	s
888.7834	s
890.3993	s
894.2073	s
920.7675	s
925.216	s
928.7843	s
933.2671	s

Table 20. Raw Data Keystrokes "x" and "z"

Time Stamp	Direction
802.9425	x
870.3827	z
915.0143	x
940.2570	z

D.2 Merged Data Set

Table 21. Merged Raw Data

Time Stamp	Direction
802.581	1
802.9425	x
803.5465	s
806.3734	2
810.1065	1
810.8215	2
813.798	1
814.3255	2
817.5901	1
818.0061	2
821.2535	1
821.7334	2
823.9101	1
824.4209	2
825.947	s
827.9464	s
829.1255	1
829.8586	2
832.5869	s
832.6738	1
835.6264	s
838.4495	2
840.6183	s
842.0974	1
842.6419	2
843.6749	s
845.579	s
846.5617	1
848.6984	s
850.4976	2
852.4817	1
852.8655	2
855.3058	s
856.5944	1
857.2497	2
858.9943	1
859.5851	2
862.6266	1
863.1863	2
865.1937	s
865.4732	1
867.9543	2
869.6048	1
870.1773	2
870.3827	z
873.870	s
876.6264	1
879.1656	s
883.0394	s
885.2598	2
888.7834	s
890.3993	s
891.1484	1
894.2073	s
896.172	2
914.9097	1
915.014	x
917.5037	2
920.7675	s
925.216	s
926.4308	1
928.7843	s
930.9109	2
933.2671	s
935.150	1
936.031	2
936.690	1
937.942	2
938.834	1
939.610	2
940.257	z
943.358	1

D.3 NCHRP Critical Headway Method 1: Gap and Lag Data

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps	
	802.581	1	V-001					**Rejected Lag** Lag = V-002 – V-001 0.965 s = 803.5465 – 802.5810
Start of Queue	802.9425	x						
	803.5465	s	V-002	0		0.965		
	806.3734	2						
	810.1065	1	V-003					
	810.8215	2						
	813.798	1	V-004					
	814.3255	2						
	817.5901	1	V-005					
	818.0061	2						
	821.2535	1	V-006					
	821.7334	2						
	823.9101	1	V-007					
	824.4209	2						
	825.947	s	V-008					
	827.9464	s	V-009					
	829.1255	1	V-010					
	829.8586	2						
	832.5869	s	V-011					
	832.6738	1	V-012					**Rejected Lag** Lag = V-013 – V-012 2.953 s = 835.6264 – 832.6738
Accepted Gap Gap = V-014 – V-013 4.992 s = 840.6183 – 835.6264	835.6264	s	V-013	0		2.953		
	838.4495	2						
	840.6183	s	V-014	1			4.992	
	842.0974	1	V-015					
	842.6419	2						
	843.6749	s	V-016					
	845.579	s	V-017					

Legend

1	Vehicle arrives at then entry point
2	Vehicle arrives at the circular roadway
s	Vehicle circulates in front of the approach of interest
x	Beginning of queue on the approach of interest
z	End of queue on the approach of interest

Rejected Gap
Rejected Lag
Accepted Gap
1+ minute queuing period

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps	
	846.5617	1	V-018					**Rejected Lag** Lag = V-019 – V-018 2.137 s = 848.6984 – 846.5617
	848.6984	s	V-019	0		2.137		
	850.4976	2						
	852.4817	1	V-020					
	852.8655	2						
	855.3058	s	V-021					
	856.5944	1	V-022					
	857.2497	2						
	858.9943	1	V-023					
	859.5851	2						
	862.6266	1	V-024					
	863.1863	2						
	865.1937	s	V-025					
	865.4732	1	V-026					
	867.9543	2						
	869.6048	1	V-027					
	870.1773	2						
End of Queue	870.3827	z						
	873.87	s	V-028					
Rejected Lag Lag = V-030 – V-029 2.539 s = 879.1656 – 876.6264	876.6264	1	V-029					
	879.1656	s	V-030	0		2.539		**Rejected Gap** Gap = V-031 – V-030 3.874 s = 883.0394 – 879.1656
Accepted Gap Gap = V-032 – V-031 5.744 s = 888.7834 – 883.0394	883.0394	s	V-031	0	3.874			
	885.2598	2						
	888.7834	s	V-032	1			5.744	
	890.3993	s	V-033					
	891.1484	1	V-034					**Rejected Lag** Lag = V-035 – V-034 3.059 s = 894.2073 – 891.1484
	894.2073	s	V-035	0		3.059		
	896.172	2						
	914.9097	1	V-037					

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period

Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
915.0143	x					
917.5037	2					
920.7675	s	V-038				
925.216	s	V-039				
926.4308	1	V-040				
928.7843	s	V-041	0		2.353	
930.9109	2					
933.2671	s	V-042	1			4.483
935.1497	1	V-043				
936.031	2					
936.690	1	V-044				
937.942	2					
938.834	1	V-045				
939.610	2					
940.257	z					
943.358	1	V-046				

Accepted Gap
Gap = V-042 – V-041
4.483 s =933.2671 – 928.7843

Rejected Lag
Lag = V-041 – V-040
2.353 s = 928.7843 – 926.4308

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

D.4 NCHRP Critical Headway Method 2: Gap and Lag Data

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
	802.581	1	V-001				
Start of Queue	802.9425	x					
	803.5465	s	V-002				
	806.3734	2					
	810.1065	1	V-003				
	810.8215	2					
	813.798	1	V-004				
	814.3255	2					
	817.5901	1	V-005				
	818.0061	2					
	821.2535	1	V-006				
	821.7334	2					
	823.9101	1	V-007				
	824.4209	2					
	825.947	s	V-008				
	827.9464	s	V-009				
	829.1255	1	V-010				
	829.8586	2					
	832.5869	s	V-011				
	832.6738	1	V-012				
	835.6264	s	V-013				
	838.4495	2					
	840.6183	s	V-014				
	842.0974	1	V-015				
	842.6419	2					
	843.6749	s	V-016				
	845.579	s	V-017				
	846.5617	1	V-018				

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps	
	848.6984	s	V-019			2.137		
	850.4976	2						
	852.4817	1	V-020					
	852.8655	2						
	855.3058	s	V-021					
	856.5944	1	V-022					
	857.2497	2						
	858.9943	1	V-023					
	859.5851	2						
	862.6266	1	V-024					
	863.1863	2						
	865.1937	s	V-025					
	865.4732	1	V-026					
	867.9543	2						
	869.6048	1	V-027					
	870.1773	2						
End of Queue	870.3827	z						
	873.87	s	V-028					
	876.6264	1	V-029					
	879.1656	s	V-030	0		2.539		**Rejected Gap** Gap = V-031 – V-030 3.874 s = 883.0394 – 879.1656
Accepted Gap Gap = V-032 – V-031 5.744 s = 888.7834 – 883.0394	883.0394	s	V-031		3.874			
	885.2598	2						
	888.7834	s	V-032	1			5.744	
	890.3993	s	V-033					
	891.1484	1	V-034					
	894.2073	s	V-035			3.059		
	896.172	2						
	914.9097	1	V-037					
	915.0143	x						
	917.5037	2						

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
920.7675	s	V-038				
925.216	s	V-039				
926.4308	1	V-040				
928.7843	s	V-041				
930.9109	2					
933.2671	s	V-042				
935.1497	1	V-043				
936.031	2					
936.690	1	V-044				
937.942	2					
938.834	1	V-045				
939.610	2					
940.257	z					
943.358	1	V-046				

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

D.5 NCHRP Critical Headway Method 3: Gap and Lag Data

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
	802.581	1	V-001				
Start of Queue	802.9425	x					
	803.5465	s	V-002				
	806.3734	2					
	810.1065	1	V-003				
	810.8215	2					
	813.798	1	V-004				
	814.3255	2					
	817.5901	1	V-005				
	818.0061	2					
	821.2535	1	V-006				
	821.7334	2					
	823.9101	1	V-007				
	824.4209	2					
	825.947	s	V-008				
	827.9464	s	V-009				
	829.1255	1	V-010				
	829.8586	2					
	832.5869	s	V-011				
	832.6738	1	V-012				
	835.6264	s	V-013				
	838.4495	2					
	840.6183	s	V-014				
	842.0974	1	V-015				
	842.6419	2					
	843.6749	s	V-016				
	845.579	s	V-017				
	846.5617	1	V-018				

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

	Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
	848.6984	s	V-019				
	850.4976	2					
	852.4817	1	V-020				
	852.8655	2					
	855.3058	s	V-021				
	856.5944	1	V-022				
	857.2497	2					
	858.9943	1	V-023				
	859.5851	2					
	862.6266	1	V-024				
	863.1863	2					
	865.1937	s	V-025				
	865.4732	1	V-026				
	867.9543	2					
	869.6048	1	V-027				
	870.1773	2					
End of Queue	870.3827	z					
	873.87	s	V-028				
	876.6264	1	V-029				
	879.1656	s	V-030				
	883.0394	s	V-031				
	885.2598	2					
	888.7834	s	V-032				
	890.3993	s	V-033				
	891.1484	1	V-034				
	894.2073	s	V-035				
	896.172	2					
	914.9097	1	V-037				
	915.0143	x					
	917.5037	2					
	920.7675	s	V-038				

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Success	Rejected Gaps	Rejected Lag	Accepted Gaps
925.216	s	V-039				
926.4308	1	V-040				
928.7843	s	V-041				
930.9109	2					
933.2671	s	V-042				
935.1497	1	V-043				
936.0309	2					
936.690	1	V-044				
937.942	2					
938.834	1	V-045				
939.610	2					
940.257	z					
943.358	1	V-046				

Legend			
1	Vehicle arrives at then entry point		Rejected Gap
2	Vehicle arrives at the circular roadway		Rejected Lag
s	Vehicle circulates in front of the approach of interest		Accepted Gap
x	Beginning of queue on the approach of interest		1+ minute queuing period
z	End of queue on the approach of interest		

D.6 Raw Data Follow-up Headways

Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
802.581	1	V-001		
802.9425	x			
803.5465	s	V-002		
806.3734	2			
810.1065	1	V-003		
810.8215	2		4.448	3.733
813.798	1	V-004		
814.3255	2		3.504	2.977
817.5901	1	V-005		
818.0061	2		3.681	3.265
821.2535	1	V-006		
821.7334	2		3.727	3.247
823.9101	1	V-007		
824.4209	2		2.688	2.177
825.947	s	V-008		
827.9464	s	V-009		
829.1255	1	V-010		
829.8586	2			
832.5869	s	V-011		
832.6738	1	V-012		
835.6264	s	V-013		
838.4495	2			
840.6183	s	V-014		
842.0974	1	V-015		
842.6419	2			
843.6749	s	V-016		
845.579	s	V-017		
846.5617	1	V-018		
848.6984	s	V-019		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
850.4976	2			
852.4817	1	V-020		
852.8655	2		2.368	1.984
855.3058	s	V-021		
856.5944	1	V-022		
857.2497	2			
858.9943	1	V-023		
859.5851	2		2.335	1.745
862.6266	1	V-024		
863.1863	2		3.601	3.041
865.1937	s	V-025		
865.4732	1	V-026		
867.9543	2			
869.6048	1	V-027		
870.1773	2		2.223	1.650
870.3827	z			
873.87	s	V-028		
876.6264	1	V-029		
879.1656	s	V-030		
883.0394	s	V-031		
885.2598	2			
888.7834	s	V-032		
890.3993	s	V-033		
891.1484	1	V-034		
894.2073	s	V-035		
896.172	2			
914.9097	1	V-037		
915.0143	x			
917.5037	2			
920.7675	s	V-038		
925.216	s	V-039		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
926.4308	1	V-040		
928.7843	s	V-041		
930.9109	2			
933.2671	s	V-042		
935.1497	1	V-043		
936.0309	2			
936.690	1	V-044		
937.942	2		1.911	0.659
938.834	1	V-045		
939.610	2		1.668	0.892
940.257	z			
943.358	1	V-046		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

D.7 Queued Data Method For Follow-up Headway

	Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
	802.581	1	V-001		
Start of Queue	802.9425	x			
	803.5465	s	V-002		
	806.3734	2			
	810.1065	1	V-003		
	810.8215	2		4.448	3.733
	813.798	1	V-004		
	814.3255	2		3.504	2.977
	817.5901	1	V-005		
	818.0061	2		3.681	3.265
	821.2535	1	V-006		
	821.7334	2		3.727	3.247
	823.9101	1	V-007		
	824.4209	2		2.688	2.177
	825.947	s	V-008		
	827.9464	s	V-009		
	829.1255	1	V-010		
	829.8586	2			
	832.5869	s	V-011		
	832.6738	1	V-012		
	835.6264	s	V-013		
	838.4495	2			
	840.6183	s	V-014		
	842.0974	1	V-015		
	842.6419	2			
	843.6749	s	V-016		
	845.579	s	V-017		
	846.5617	1	V-018		
	848.6984	s	V-019		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

	Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
	850.4976	2			
	852.4817	1	V-020		
	852.8655	2		2.368	1.984
	855.3058	s	V-021		
	856.5944	1	V-022		
	857.2497	2			
	858.9943	1	V-023		
	859.5851	2		2.335	1.745
	862.6266	1	V-024		
	863.1863	2		3.601	3.041
	865.1937	s	V-025		
	865.4732	1	V-026		
	867.9543	2			
	869.6048	1	V-027		
	870.1773	2		2.223	1.650
End of Queue	870.3827	z			
	873.87	s	V-028		
	876.6264	1	V-029		
	879.1656	s	V-030		
	883.0394	s	V-031		
	885.2598	2			
	888.7834	s	V-032		
	890.3993	s	V-033		
	891.1484	1	V-034		
	894.2073	s	V-035		
	896.172	2			
	914.9097	1	V-037		
	915.0143	x			
	917.5037	2			
	920.7675	s	V-038		
	925.216	s	V-039		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
915.0143	x			
917.5037	2			
920.7675	s	V-038		
925.216	s	V-039		
926.4308	1	V-040		
928.7843	s	V-041		
930.9109	2			
933.2671	s	V-042		
935.1497	1	V-043		
936.0309	2			
936.690	1	V-044		
937.942	2			
938.834	1	V-045		
939.61	2			
940.257	z			
943.358	1	V-046		

Legend	
1	Vehicle arrives at then entry point
2	Vehicle arrives at the circular roadway
s	Vehicle circulates in front of the approach of interest
x	Beginning of queue on the approach of interest
z	End of queue on the approach of interest

D.8 Move-up Method for Follow-up Headway

For this example it is assumed that the move-up time threshold is 5 seconds.

	Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
	802.581	1	V-001		
Start of Queue	802.9425				
	803.5465	s	V-002		
	806.3734	2			
	810.1065	1	V-003		
	810.8215	2		4.448	3.733
	813.798	1	V-004		
	814.3255	2		3.504	2.977
	817.5901	1	V-005		
	818.0061	2		3.681	3.265
	821.2535	1	V-006		
	821.7334	2		3.727	3.247
	823.9101	1	V-007		
	824.4209	2		2.688	2.177
	825.947	s	V-008		
	827.9464	s	V-009		
	829.1255	1	V-010		
	829.8586	2			
	832.5869	s	V-011		
	832.6738	1	V-012		
	835.6264	s	V-013		
	838.4495	2			
	840.6183	s	V-014		
	842.0974	1	V-015		
	842.6419	2			
	843.6749	s	V-016		
	845.579	s	V-017		
	846.5617	1	V-018		
	848.6984	s	V-019		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

	Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
	850.4976	2			
	852.4817	1	V-020		
	852.8655	2		2.368	1.984
	855.3058	s	V-021		
	856.5944	1	V-022		
	857.2497	2			
	858.9943	1	V-023		
	859.5851	2		2.335	1.745
	862.6266	1	V-024		
	863.1863	2		3.601	3.041
	865.1937	s	V-025		
	865.4732	1	V-026		
	867.9543	2			
	869.6048	1	V-027		
	870.1773	2		2.223	1.650
End of Queue	870.3827	z			
	873.87	s	V-028		
	876.6264	1	V-029		
	879.1656	s	V-030		
	883.0394	s	V-031		
	885.2598	2			
	888.7834	s	V-032		
	890.3993	s	V-033		
	891.1484	1	V-034		
	894.2073	s	V-035		
	896.172	2			
	914.9097	1	V-037		
	915.0143	x			
	917.5037	2			
	920.7675	s	V-038		
	925.216	s	V-039		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

Time Stamp	Direction	Vehicle ID	Follow-Up Headway	Move-up Time
915.0143	x			
917.5037	2			
920.7675	s	V-038		
925.216	s	V-039		
926.4308	1	V-040		
928.7843	s	V-041		
930.9109	2			
933.2671	s	V-042		
935.1497	1	V-043		
936.0309	2			
936.690	1	V-044		
937.942	2		1.911	0.659
938.834	1	V-045		
939.61	2		1.668	0.892
940.257	z			
943.358	1	V-046		

Legend			
1	Vehicle arrives at then entry point		1+ minute queuing period
2	Vehicle arrives at the circular roadway		
s	Vehicle circulates in front of the approach of interest		
x	Beginning of queue on the approach of interest		
z	End of queue on the approach of interest		

APPENDIX E: GDOT DISTRICT MAP WITH DATA COLLECTION SITES

APPENDIX F: ROUNDABOUT APPROACH DATA SHEETS

Table 22. Data summary sheet for Alpharetta southbound approach

	Alpharetta
	ALP01-SB
	Southbound
	Douglas Rd./Southlake Dr./Leeward Walk Cir.
	Fulton
	Alpharetta
	7
	9930
	Tuesday, November 13, 2012
	7:18 AM – 9:15 AM
	1:57:00
inute long	3
nutes	3

	Total data	vph data
	627	322
les	640	329
	1451	745

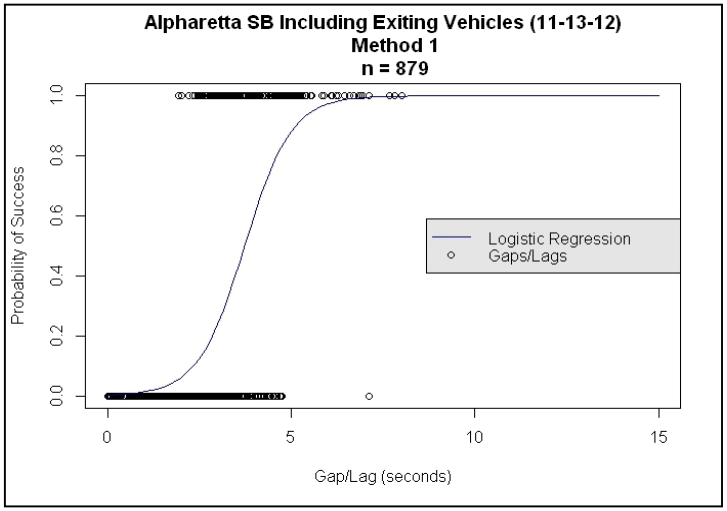
Source: Google Earth™, accessed 8/16/2013

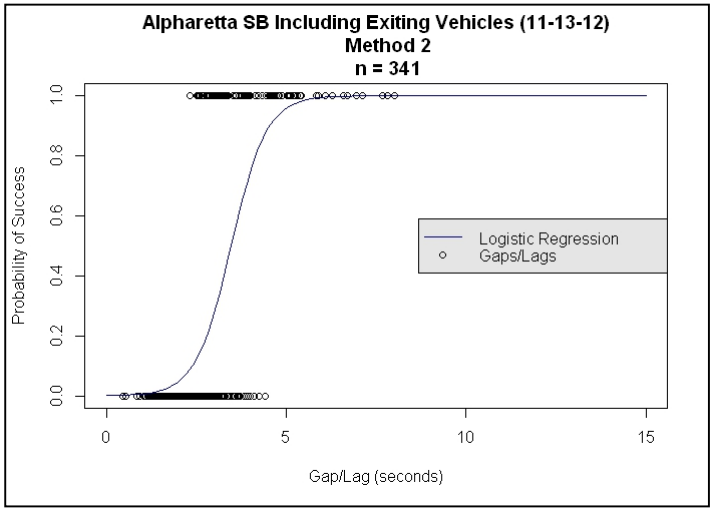
	Accepted gaps		Accepted lags		Rejected gaps		Rejected lags	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
	4.405 (2.5)	211	3.930 (3.2)	182	2.464 (0.8)	350	1.841 (1.0)	318
	8.966 (5.5)	52	8.459 (7.3)	131	3.006 (1.5)	103	2.043 (1.6)	166

	Queued Data		Move-up Data		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
	2.624 (n/a)	1	3.6	2.813 (0.7)	118
	4.035 (1.8)	18	4.0	3.412 (1.1)	248

	NCHRP Method 1		NCHRP Method 2		NCHRP Method 3	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
	3.734 (1.8)	879	3.467 (1.7)	341	2.960 (1.0)	26
	6.018 (3.6)	321	5.299 (5.4)	56	3.623 (1.4)	7

f observations; tc = critical headway; std. dev. = standard deviation
ng all user defined queuing periods > 1 minute
rmined using move-up time thresholds from > 1 minute user defined
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





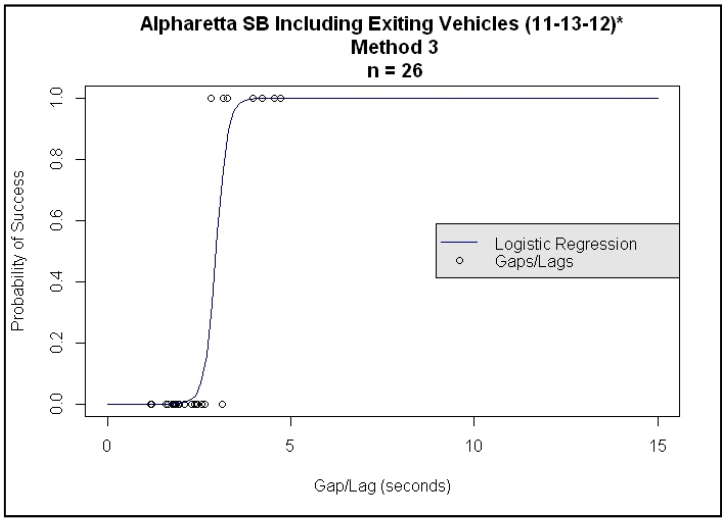
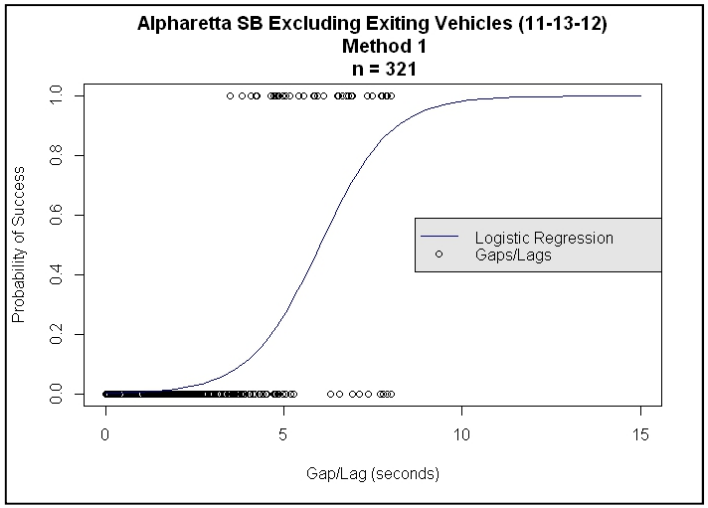
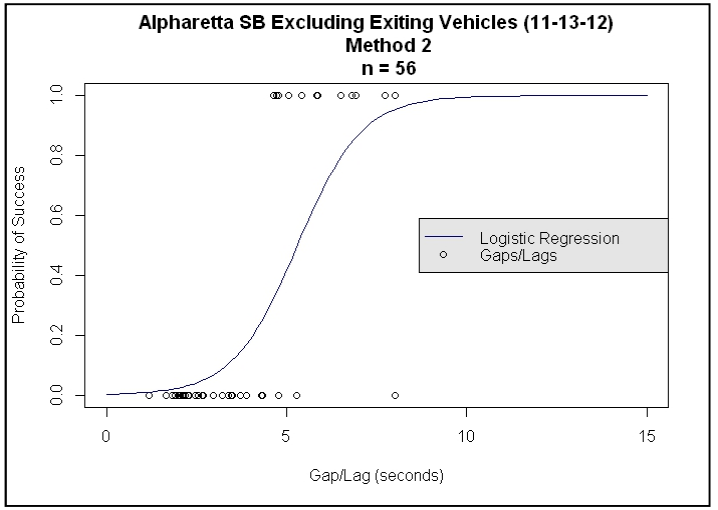


Figure 39.Critical headway including exiting vehicles for Alpharetta southbound approach





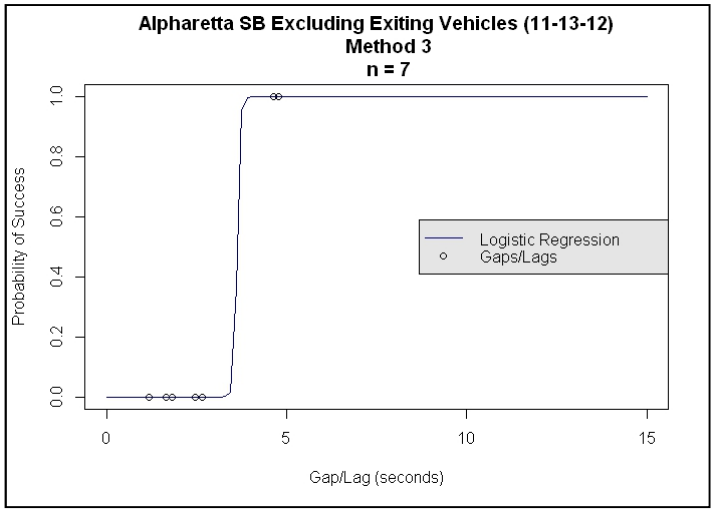
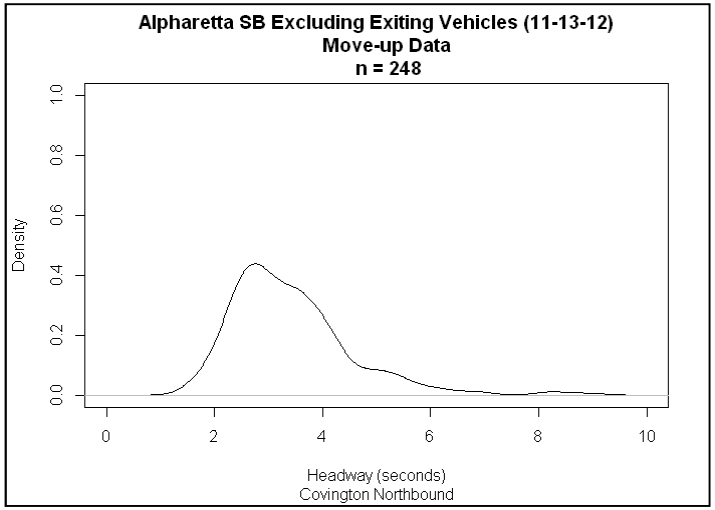
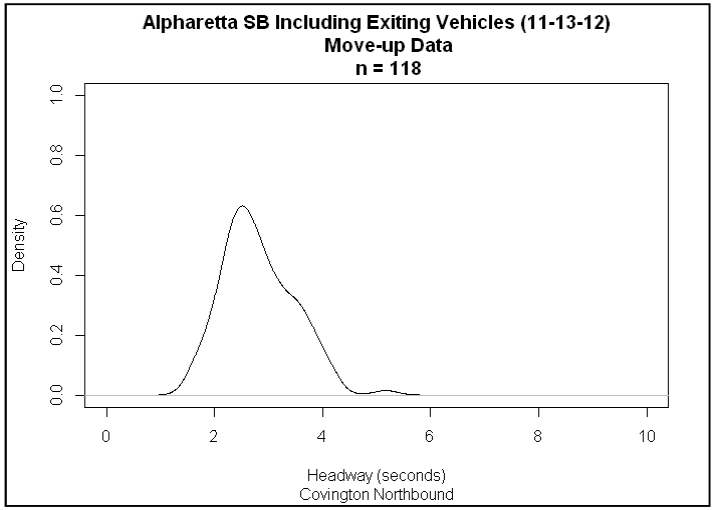
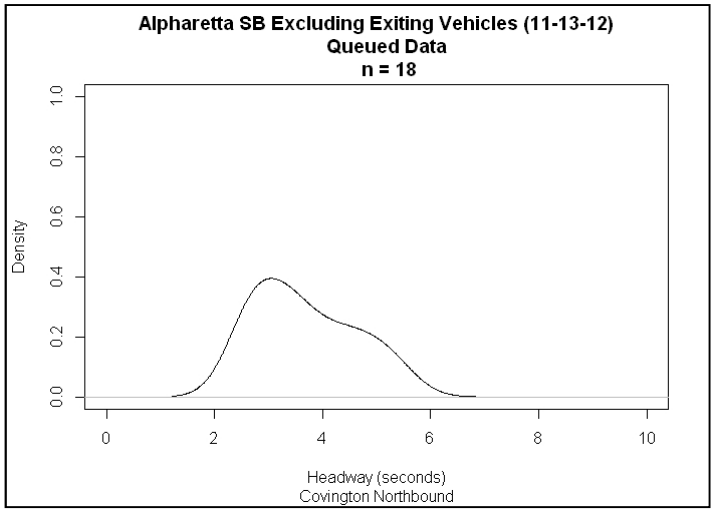


Figure 40. Critical headway excluding exiting vehicles for Alpharetta southbound approach







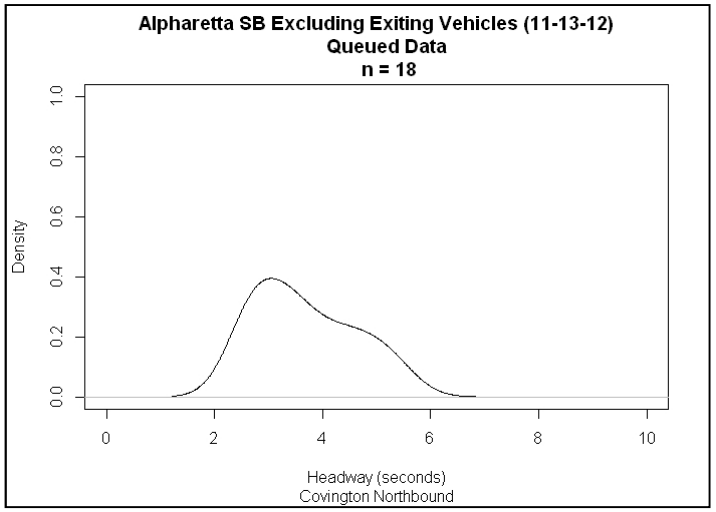


Figure 41. Follow-up headway for Alpharetta southbound approach

Table 23. Data summary sheet for Covington southbound approach

Site	Covington		
ID	COV01-SB		
Approach	Southbound		
Intersection	Turner Lake Rd. NW/Clark St. SW		
County	Newton		
City	Covington		
GDOT District	2		
AADT	8110		
Date of data collection	Thursday, March 1, 2012		
Time of data collection	4:20 PM – 7:00 PM		
Video duration	2:40:00		
Queuing periods at least 1 minute long	16		
Total number of queued minutes	87		
	Total data	vph data	
Number of entering vehicles	1876	704	
Number of circulating vehicles	438	165	
Number of exiting vehicles	1528	573	

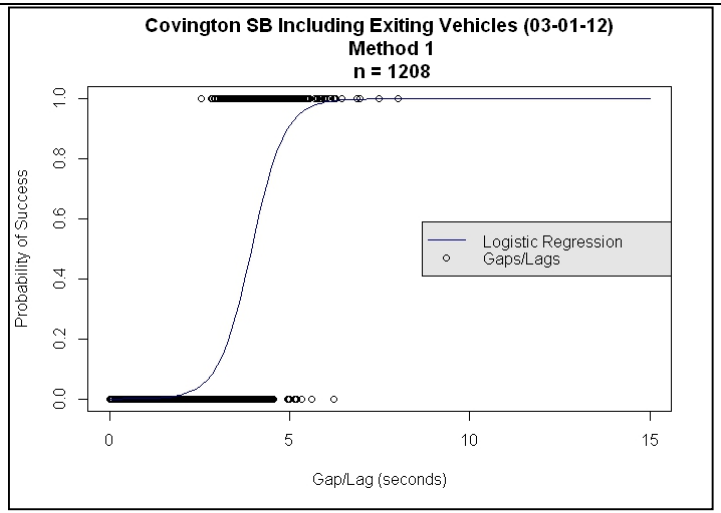
Source: Google Earth™, accessed 8/16/2013

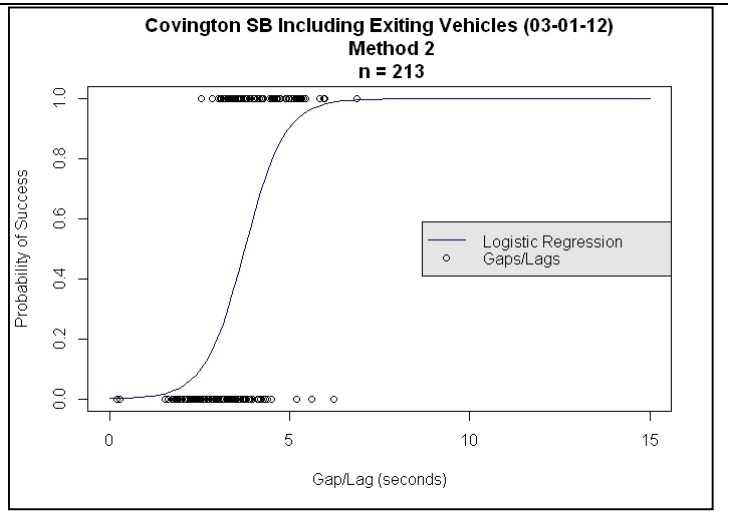
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	4.362 (0.9)	280	3.027 (1.2)	579	2.877 (0.9)	294	2.142 (0.9)	634
Excluding exiting vehicles	5.319 (1.1)	11	3.600 (4.0)	100	2.743 (1.0)	73	1.805 (1.4)	246

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.778 (0.8)	514	3.6	2.635 (0.6)	415
Excluding exiting vehicles	3.477 (1.3)	1167	4.0	3.348 (1.1)	1339

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	3.943 (1.8)	1208	3.755 (1.1)	213	3.715 (1.1)	186
Excluding exiting vehicles	6.533 (1.5)	330	3.464 (1.8)	4	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





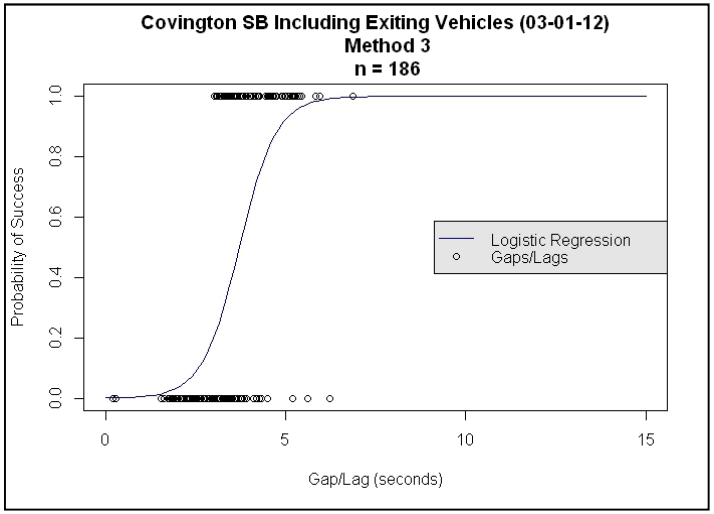
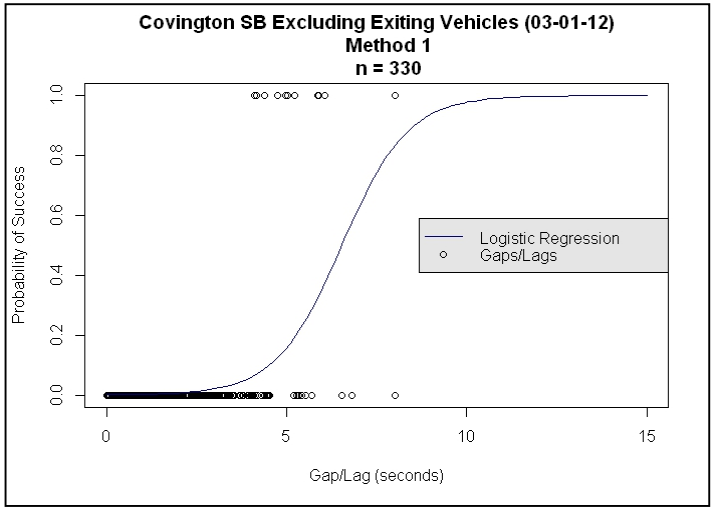


Figure 42. Critical headway including exiting vehicles for Covington southbound approach



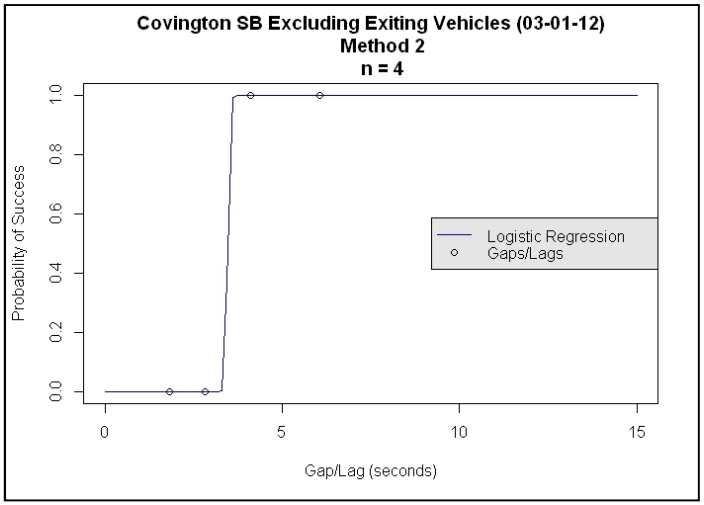


Figure 43. Critical headway excluding exiting vehicles for Covington southbound approach

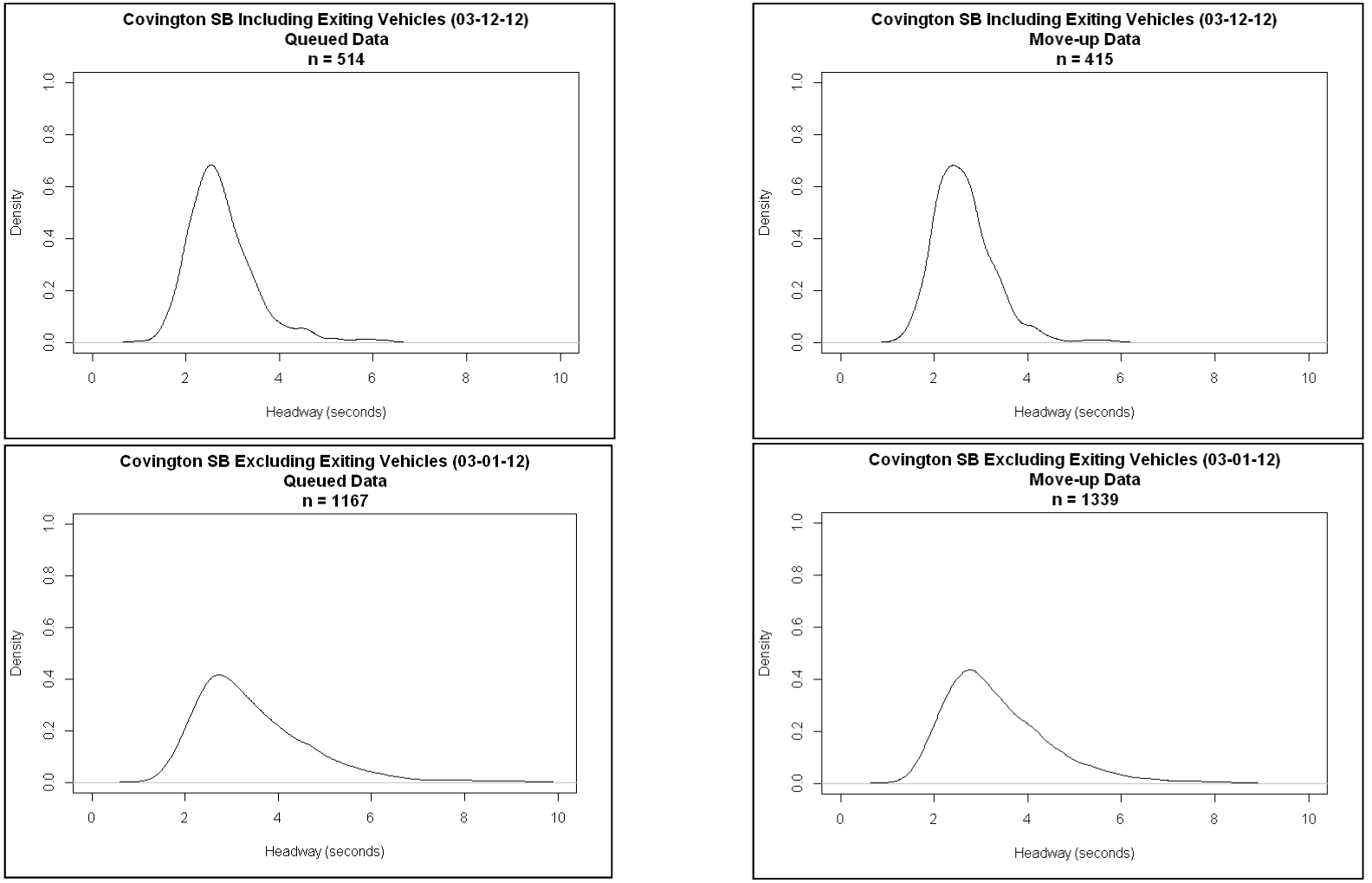


Figure 44. Follow-up headway for Covington southbound approach

Table 24. Data summary sheet for Covington northbound approach

Site	Covington		
ID	COV01-NB		
Approach	Northbound		
Intersection	Turner Lake Rd. NW/Clark St. SW		
County	Newton		
City	Covington		
GDOT District	2		
AADT	8110		
Date of data collection	Thursday, March 1, 2012		
Time of data collection	4:20 PM – 7:00 PM		
Video duration	2:40:00		
Queuing periods at least 1 minute long	22		
Total number of queued minutes	49		
	Total data	vph data	
Number of entering vehicles	1527	573	
Number of circulating vehicles	390	147	
Number of exiting vehicles	2025	760	

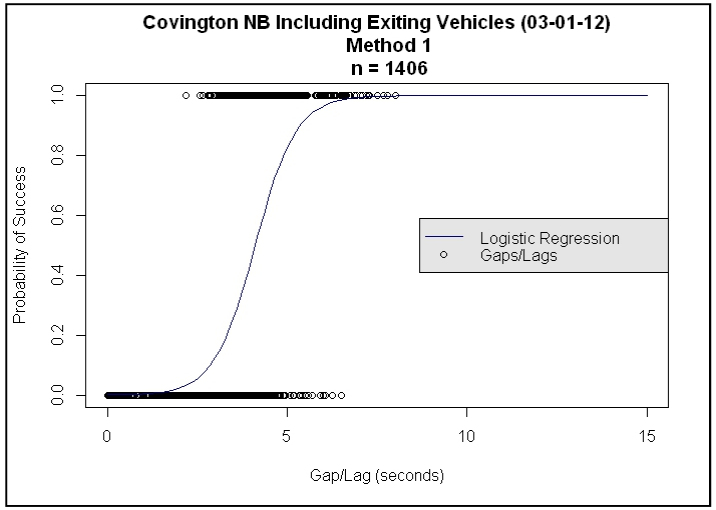
Source: Google Earth™, accessed 8/16/2013

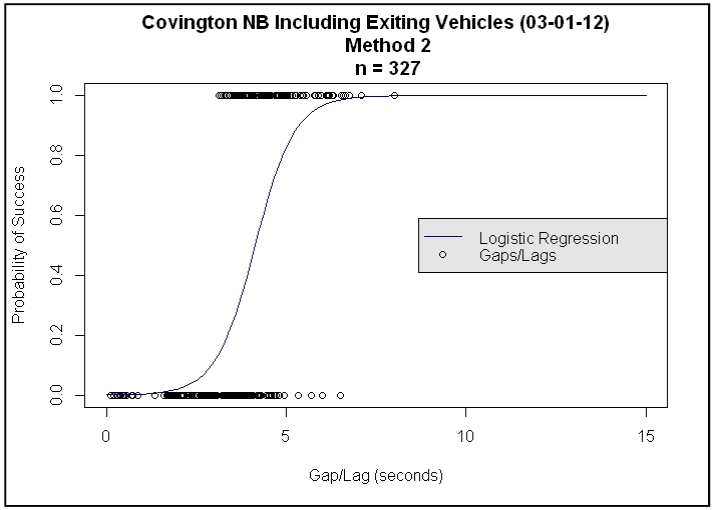
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	4.519 (1.2)	367	3.016 (1.6)	510	3.277 (1.2)	360	2.498 (0.9)	679
Excluding exiting vehicles	8.125 (2.8)	21	4.530 (3.2)	97	2.771 (1.4)	46	2.255 (1.6)	196

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.736 (0.7)	170	3.6	2.775 (0.7)	241
Excluding exiting vehicles	3.792 (1.5)	637	4.0	3.687 (1.4)	1059

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.109 (1.4)	1406	4.138 (1.6)	327	4.158 (1.4)	171
Excluding exiting vehicles	6.784 (2.0)	263	4.366 (2.9)	12	4.918 (3.1)	8

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





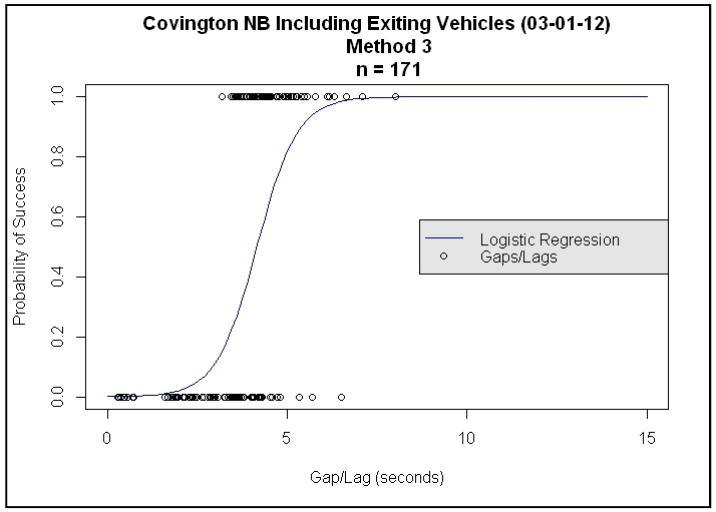
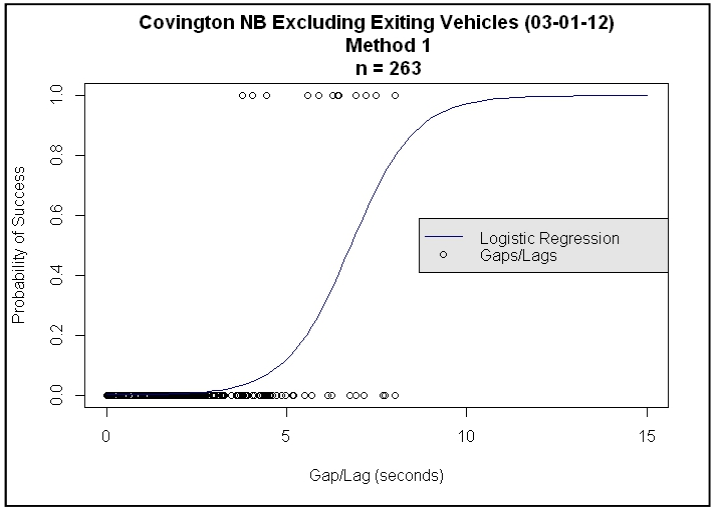
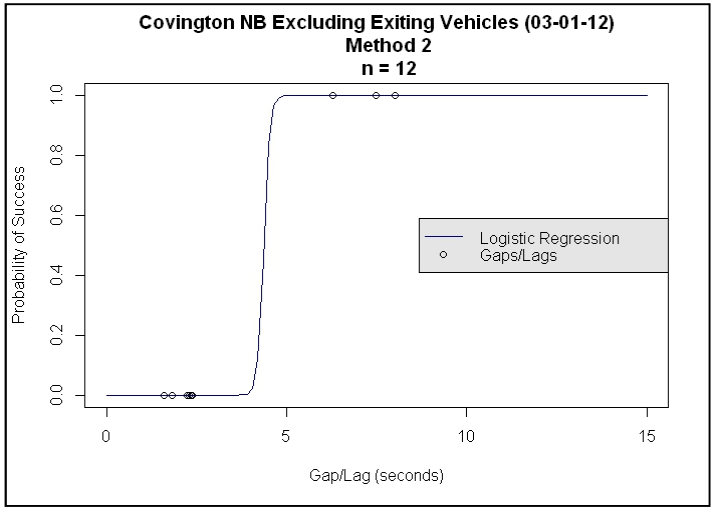


Figure 45. Critical headway including exiting vehicles for Covington northbound approach





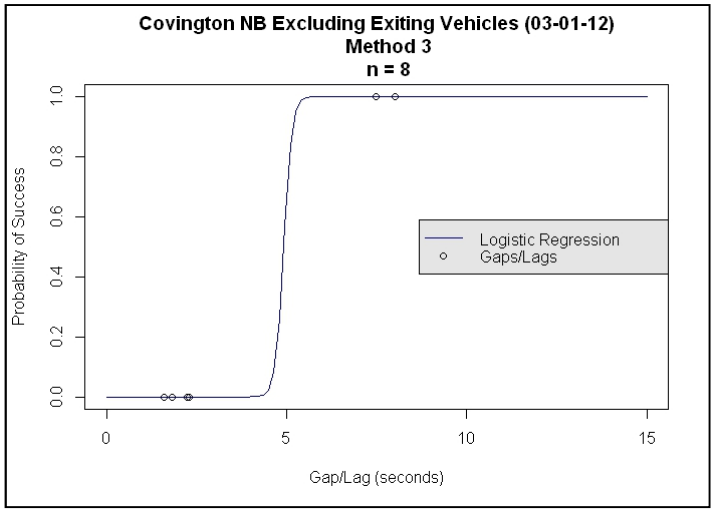


Figure 46. Critical headway excluding exiting vehicles for Covington northbound approach

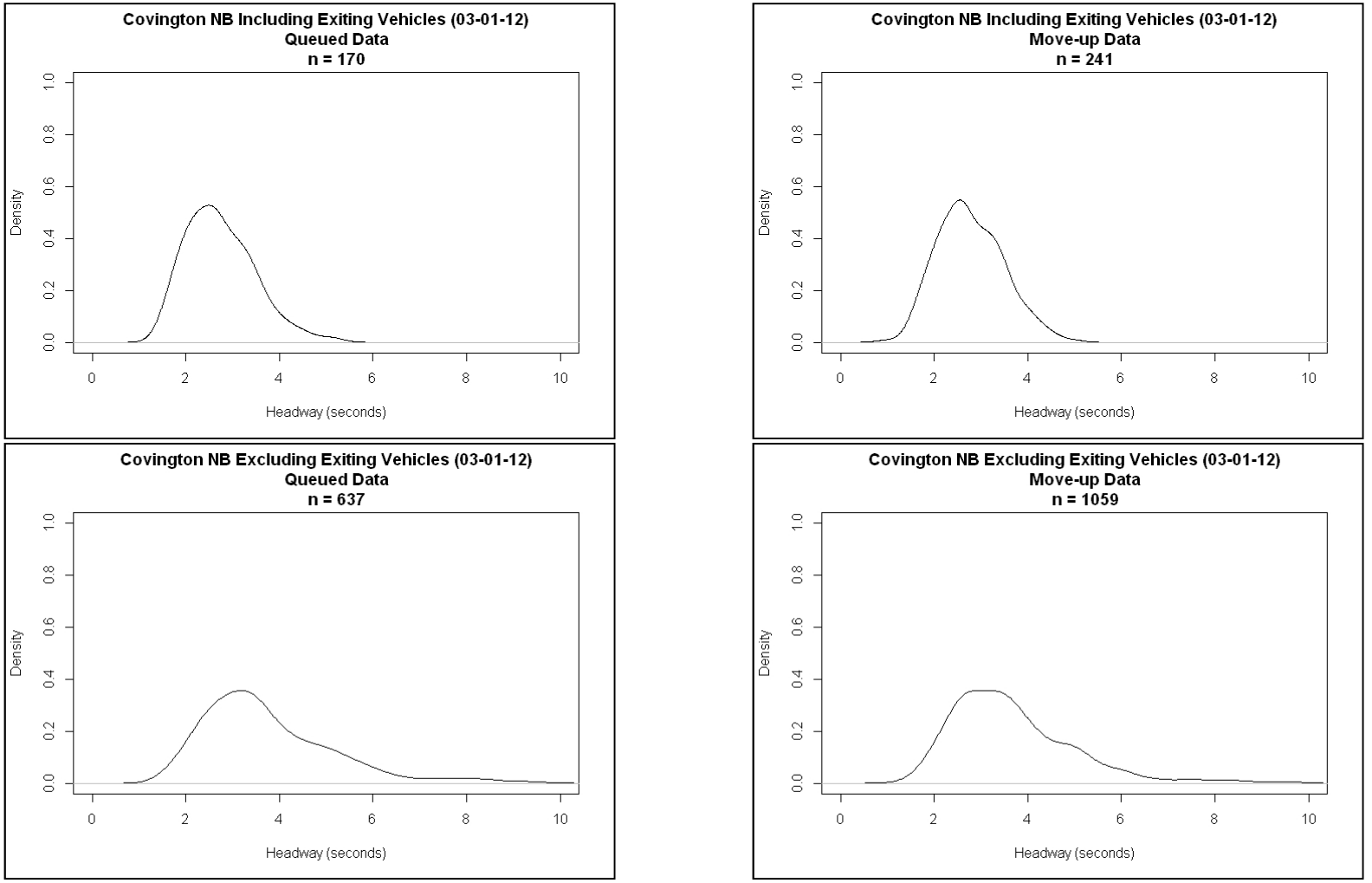


Figure 47. Follow-up headway for Covington northbound approach

Table 25. Data summary sheet for Covington westbound approach

Site	Covington		
ID	COV01-WB		
Approach	Westbound		
Intersection	Turner Lake Rd. NW/Clark St. SW		
County	Newton		
City	Covington		
GDOT District	2		
AADT	8110		
Date of data collection	Thursday, May 24, 2012		
Time of data collection	4:30 PM – 6:45 PM		
Video duration	2:15:00		
Queuing periods at least 1 minute long	2		
Total number of queued minutes	2		
	Total data	vph data	
Number of entering vehicles	569	253	
Number of circulating vehicles	1282	570	
Number of exiting vehicles	487	217	

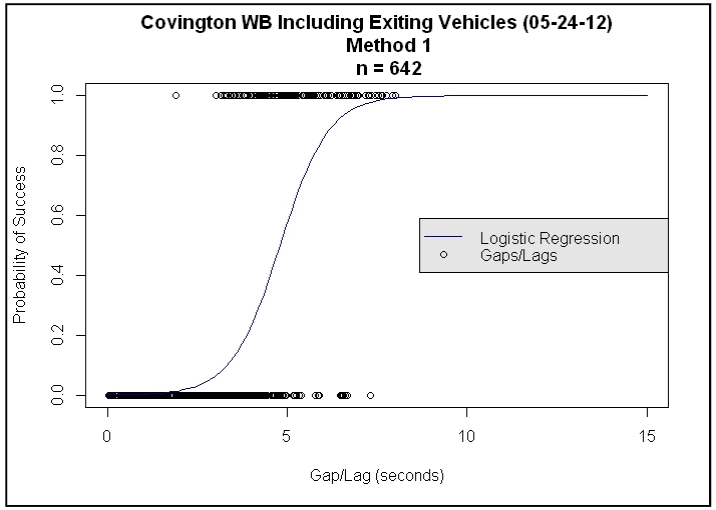
Source: Google Earth™, accessed 8/16/2013

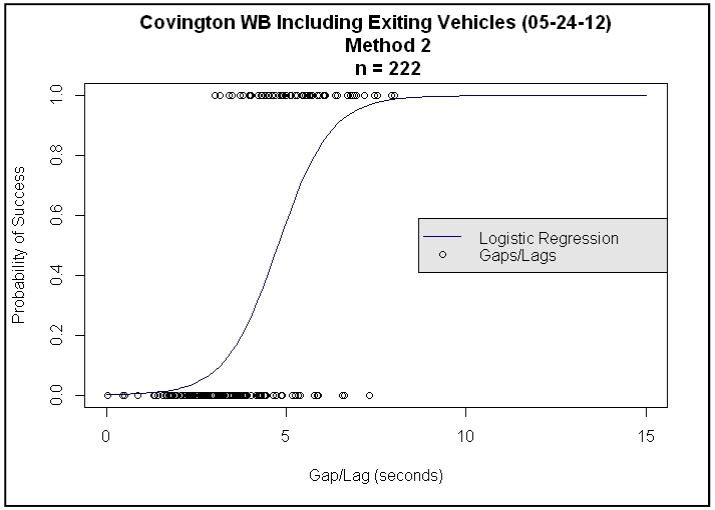
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.518 (3.3)	156	5.335 (4.2)	174	3.092 (1.1)	249	2.058 (1.3)	237
Excluding exiting vehicles	7.970 (5.0)	96	6.161 (5.6)	170	2.916 (1.1)	185	1.784 (1.2)	190

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.503 (1.2)	7	3.6	2.575 (0.7)	117
Excluding exiting vehicles	3.160 (1.6)	11	4.0	2.966 (1.4)	169

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.800 (1.9)	642	4.774 (1.7)	222	4.133 (1.3)	11
Excluding exiting vehicles	4.957 (2.0)	471	4.330 (1.9)	129	4.263 (1.1)	10

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





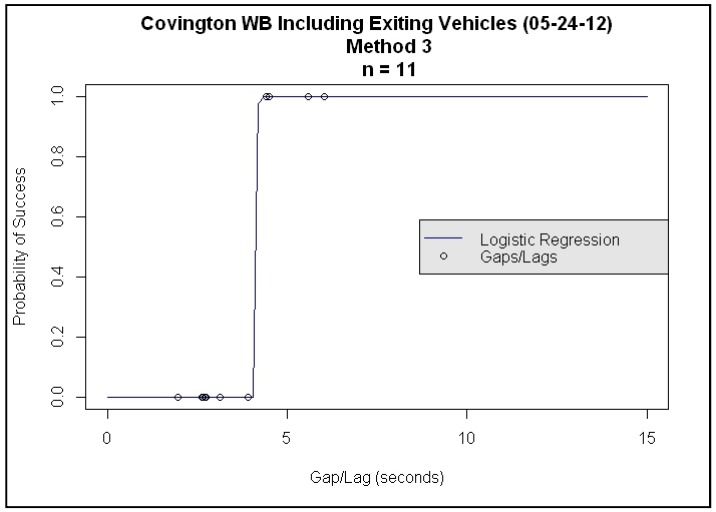
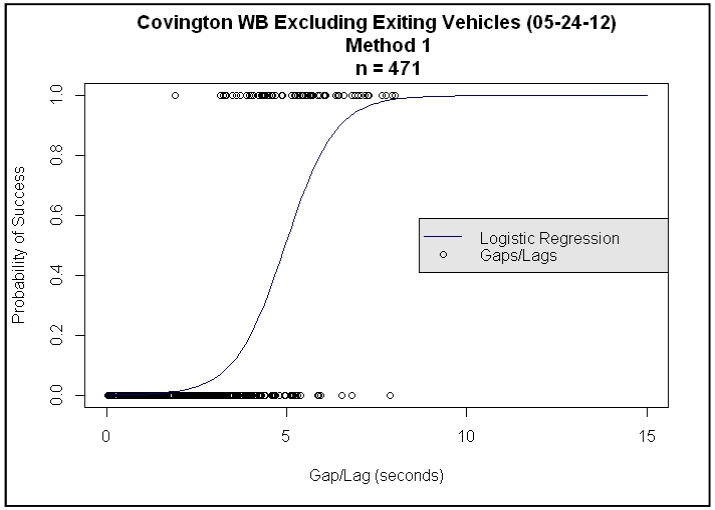
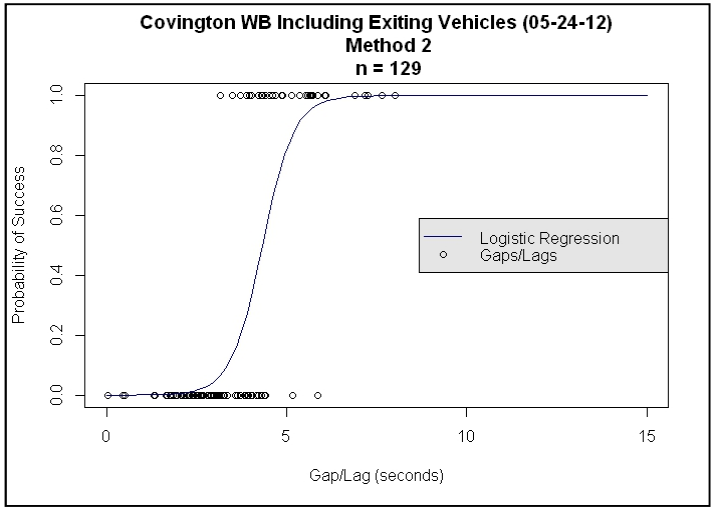


Figure 48. Critical headway including exiting vehicles for Covington westbound approach





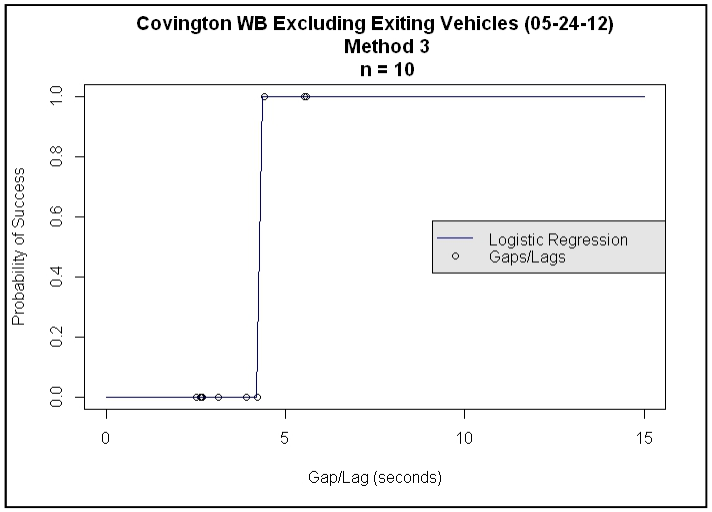


Figure 49. Critical headway excluding exiting vehicles for Covington westbound approach

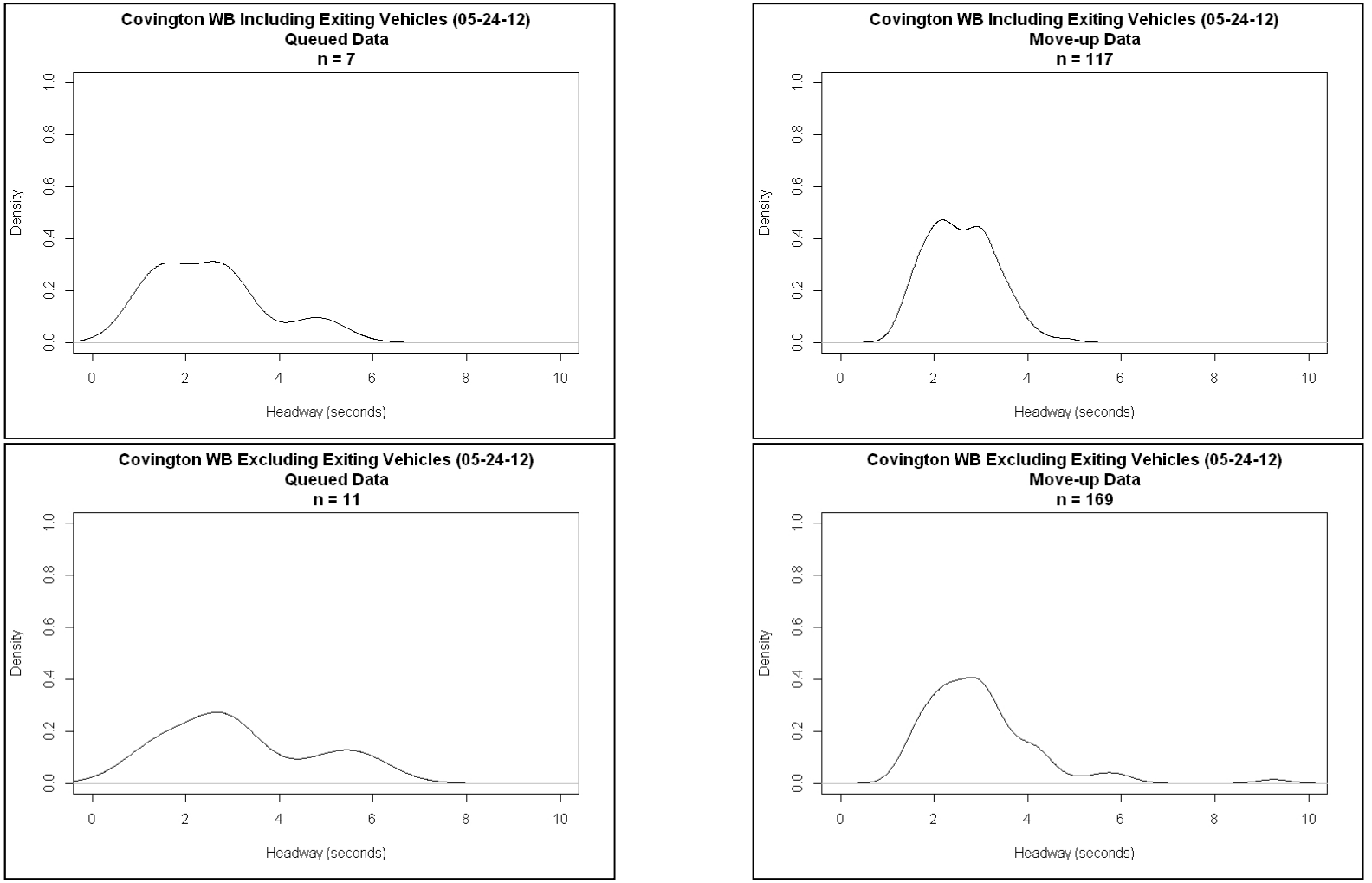


Figure 50. Follow-up headway for Covington westbound approach

Table 26. Data summary sheet for Covington eastbound approach

Site	Covington		
ID	COV01-EB		
Approach	Eastbound		
Intersection	Turner Lake Rd. NW/Clark St. SW		
County	Newton		
City	Covington		
GDOT District	2		
AADT	8110		
Date of data collection	Thursday, May 24, 2012		
Time of data collection	4:30 PM – 6:45 PM		
Video duration	2:15:00		
Queuing periods at least 1 minute long	1		
Total number of queued minutes	1		
	Total data	vph data	
Number of entering vehicles	305	136	
Number of circulating vehicles	2107	937	
Number of exiting vehicles	722	321	

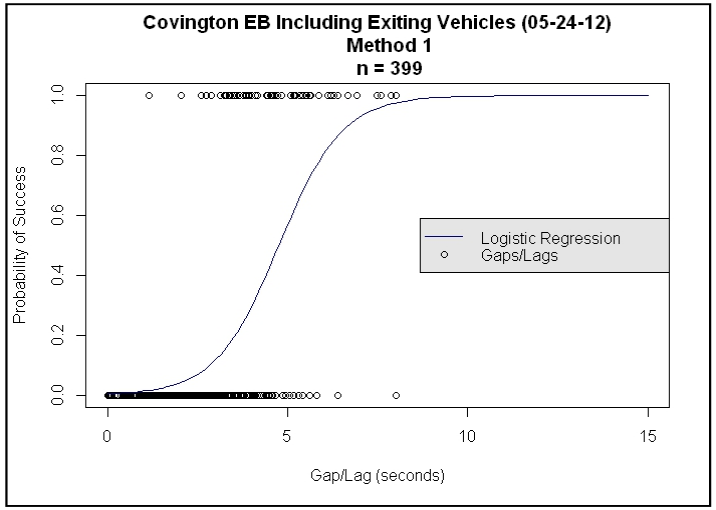
Source: Google Earth™, accessed 8/16/2013

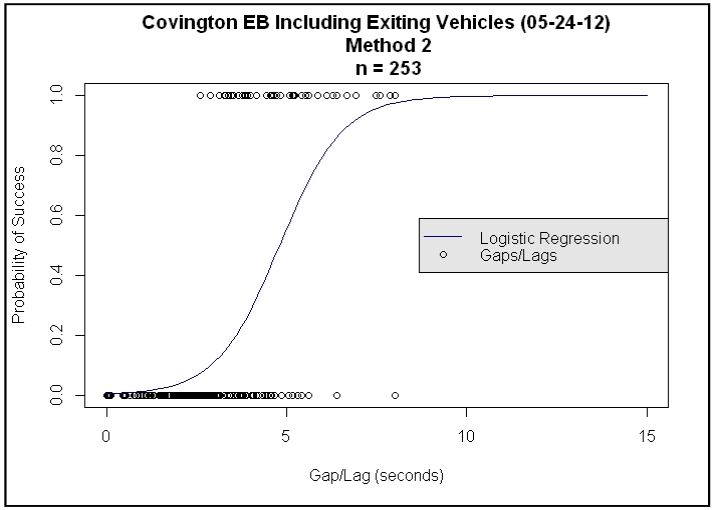
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	5.302 (3.1)	66	4.507 (2.9)	20	2.023 (1.5)	256	1.866 (1.1)	77
Excluding exiting vehicles	6.216 (4.0)	62	4.501 (2.9)	24	1.941 (1.6)	235	1.966 (1.3)	73

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	1.129 (n/a)	1	3.6	2.204 (0.9)	3
Excluding exiting vehicles	1.129 (n/a)	1	4.0	2.655 (0.9)	5

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.759 (1.8)	399	4.808 (1.9)	253	6.743 (1.8)	35
Excluding exiting vehicles	4.932 (2.0)	370	4.949 (2.1)	232	7.028 (2.0)	33

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





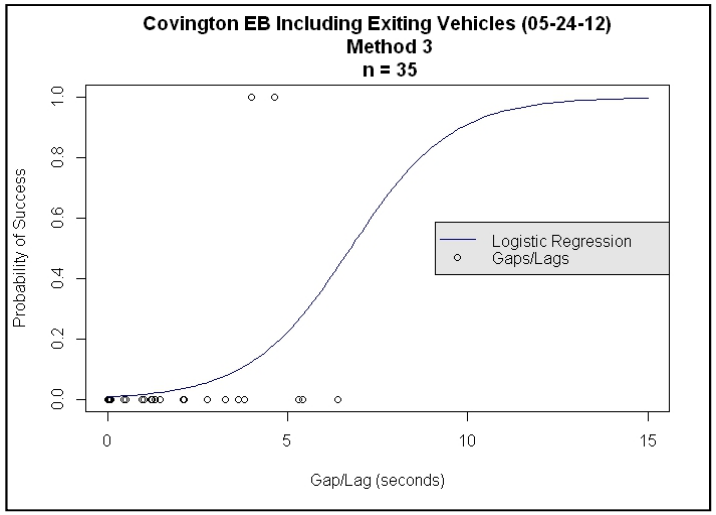
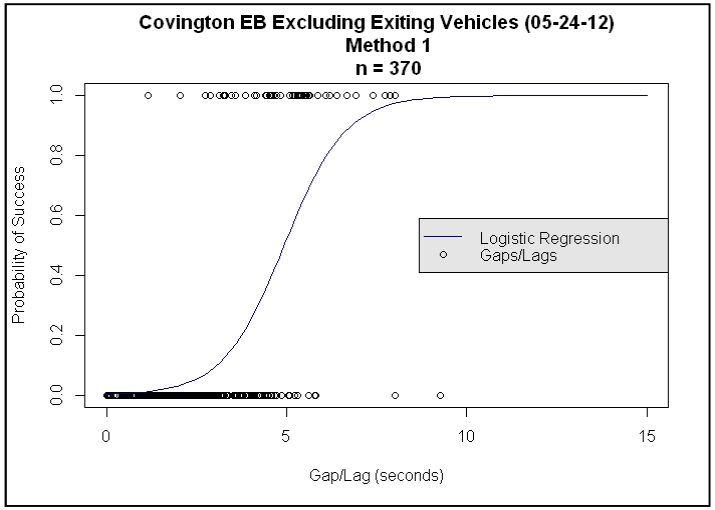
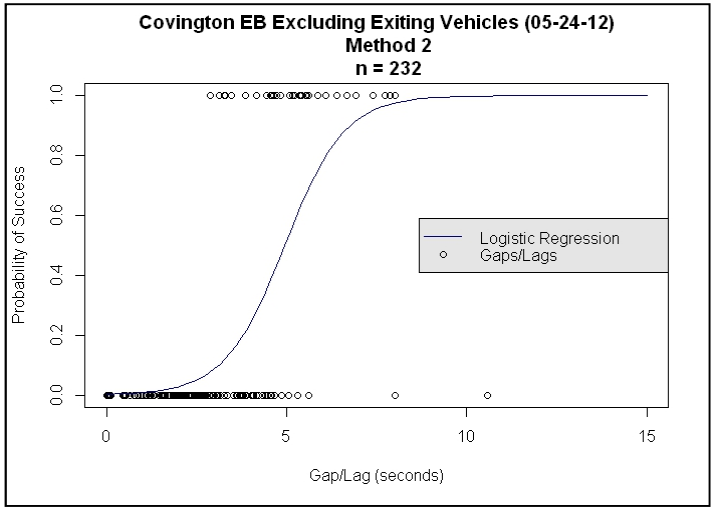


Figure 51. Critical headway including exiting vehicles for Covington eastbound approach





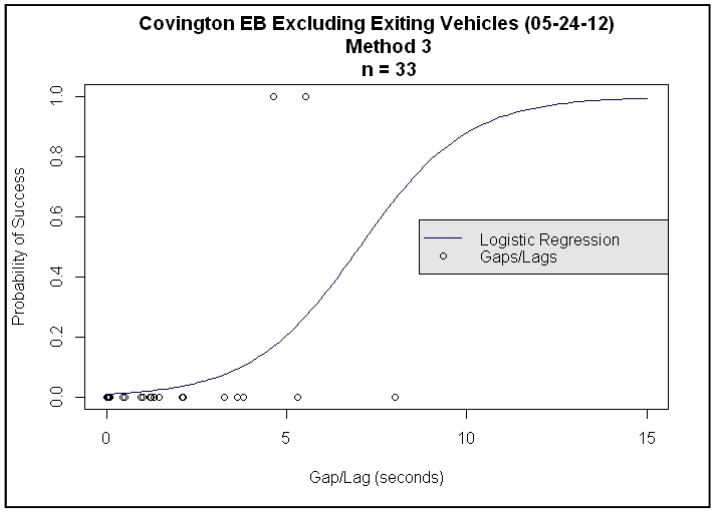


Figure 52. Critical headway excluding exiting vehicles for Covington eastbound approach

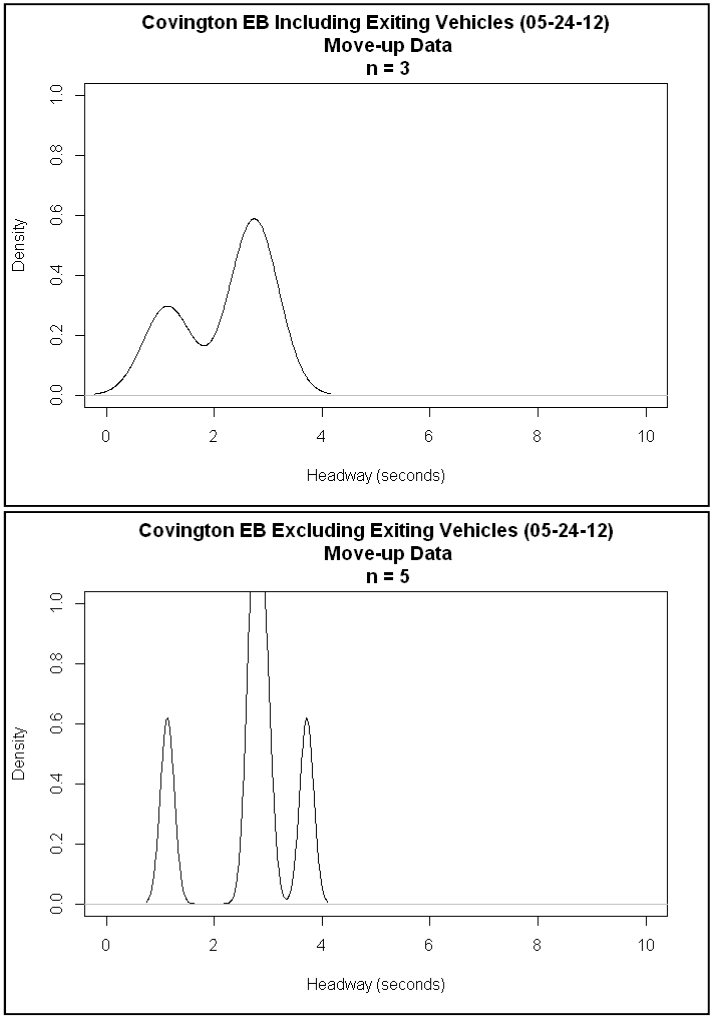


Figure 53. Follow-up headway for Covington eastbound approach

Table 27. Data summary sheet for Columbus southeastbound approach

Site	Columbus		
ID	COL01-SEB		
Approach	Southeastbound		
Intersection	Blackmon Rd./Warm Springs Rd.		
County	Muscogee		
City	Columbus		
GDOT District	3		
AADT	n/a		
Date of data collection	Friday, November 02, 2012		
Time of data collection	4:17 PM – 5:56 PM		
Video duration	1:39:00		
Queuing periods at least 1 minute long	1		
Total number of queued minutes	1		
	Total data	vph data	
Number of entering vehicles	544	330	
Number of circulating vehicles	489	297	
Number of exiting vehicles	691	419	

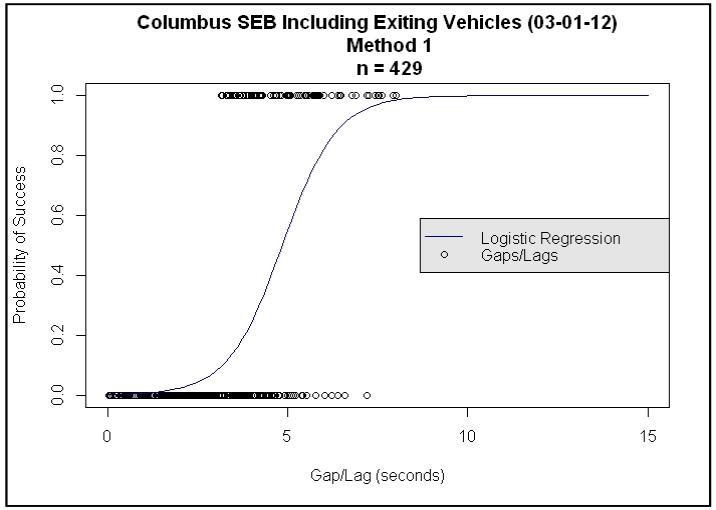
Source: Google Earth™, accessed 8/16/2013

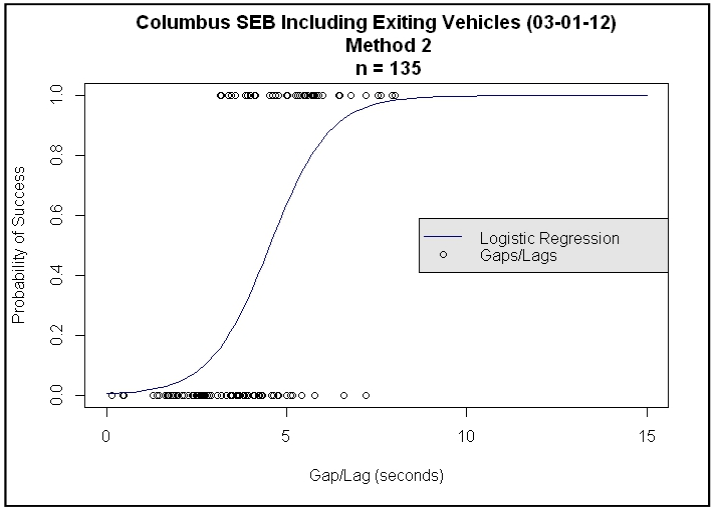
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.815 (4.6)	99	4.989 (3.5)	184	3.039 (1.2)	141	2.196 (1.2)	189
Excluding exiting vehicles	10.673 (6.9)	30	8.805 (7.9)	112	3.187 (1.3)	60	2.220 (1.6)	132

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	3.271 (1.1)	5	3.6	2.972 (0.8)	107
Excluding exiting vehicles	3.701 (1.4)	6	4.0	3.375 (1.0)	158

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.851 (1.9)	429	4.538 (1.9)	135	3.833 (1.1)	8
Excluding exiting vehicles	6.145 (2.1)	222	4.382 (2.1)	16	4.318 (1.0)	6

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





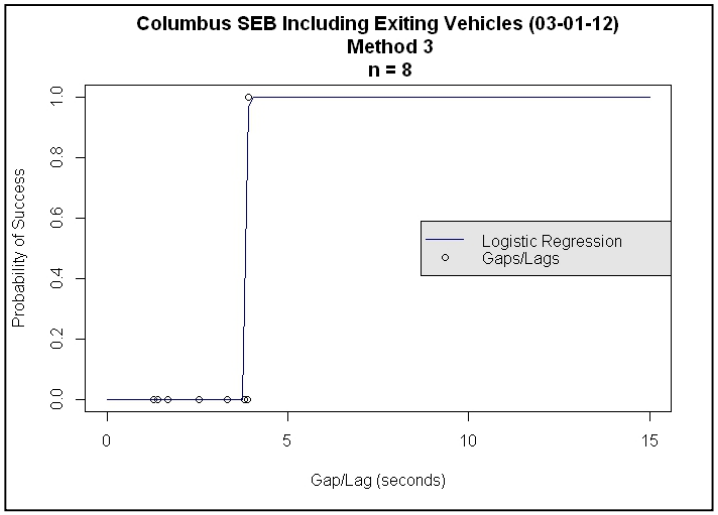
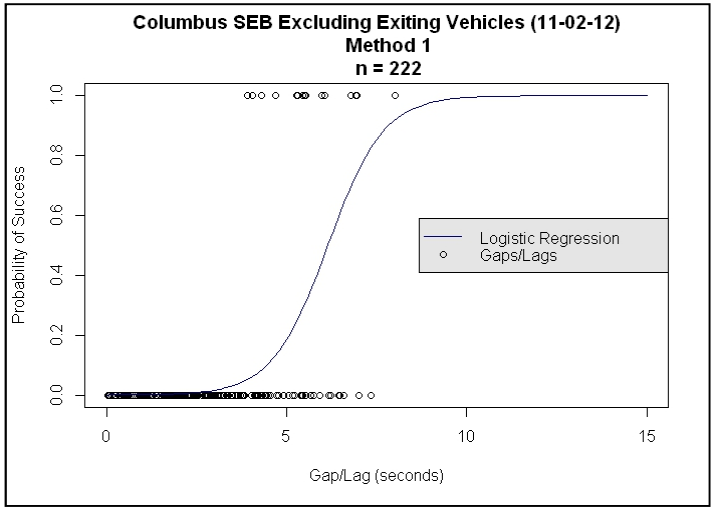
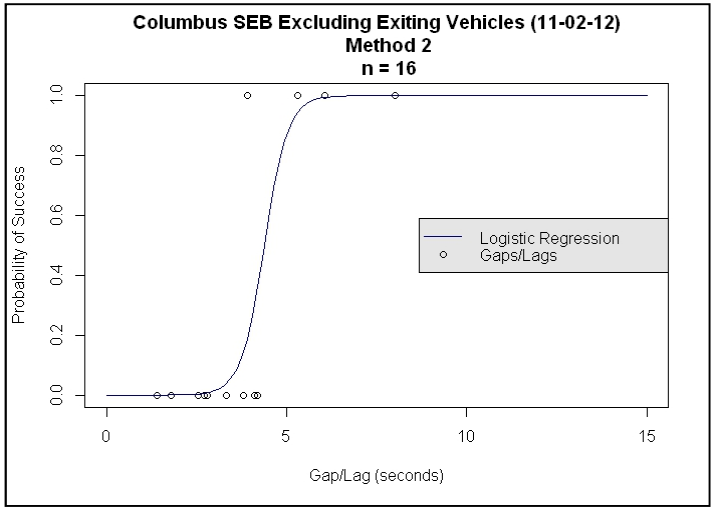


Figure 54. Critical headway including exiting vehicles for Columbus southeastbound approach





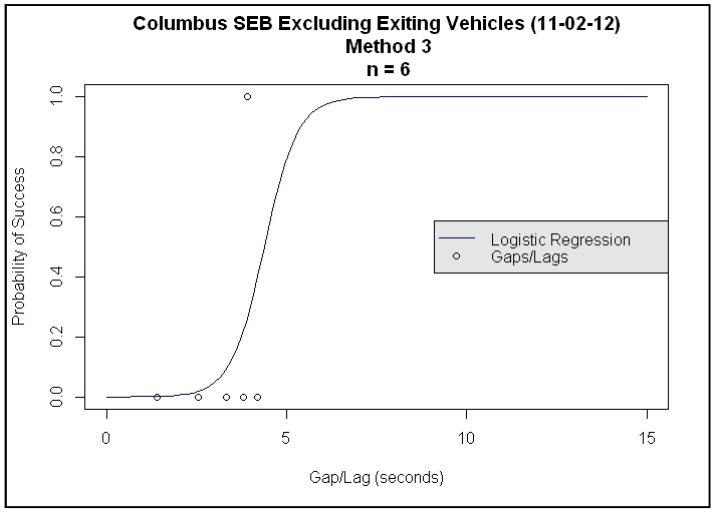


Figure 55. Critical headway excluding exiting vehicles for Columbus southeastbound approach

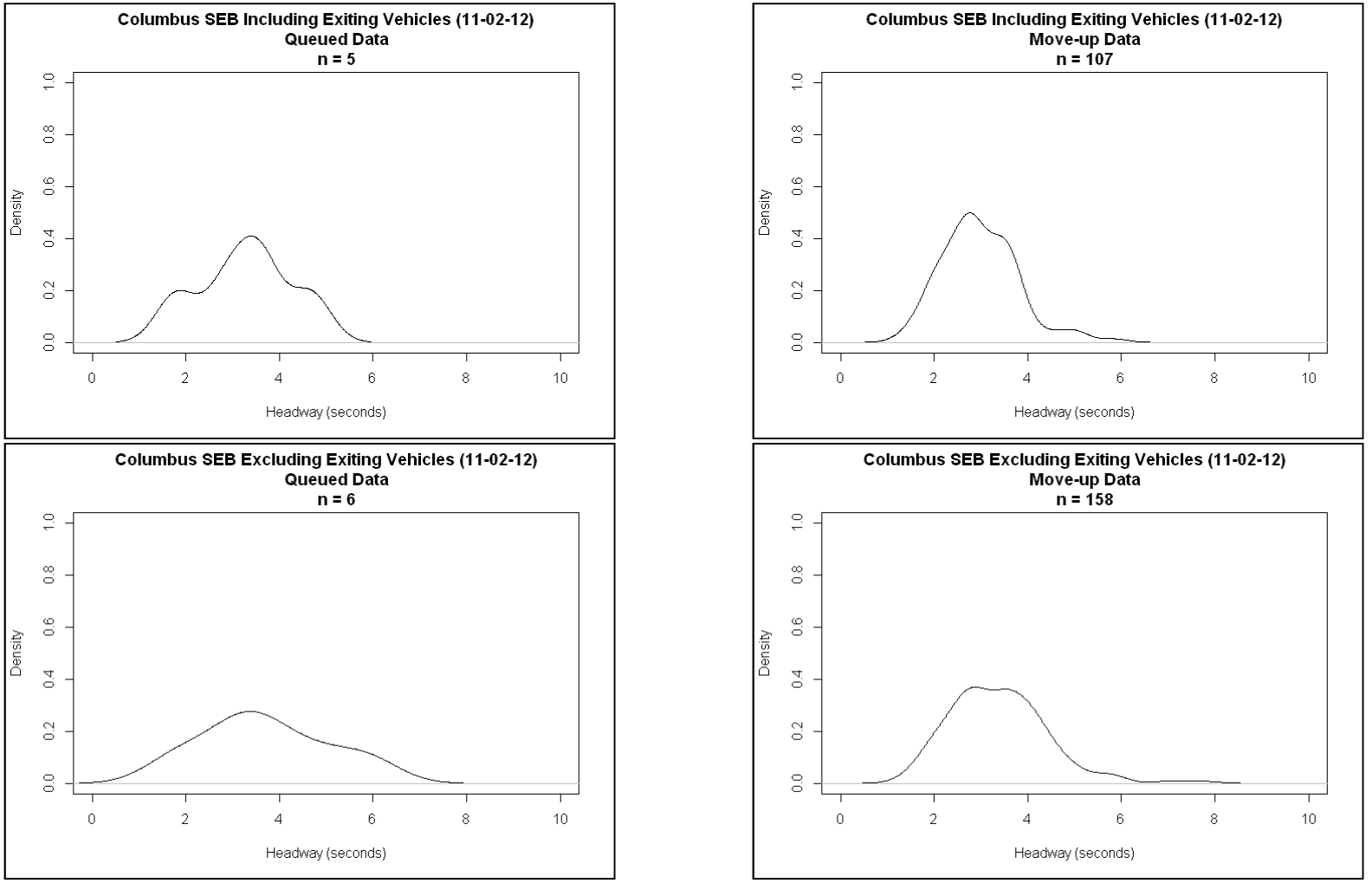


Figure 56. Follow-up headway for Columbus southeastbound approach

Table 28. Data summary sheet for Columbus southwestbound approach

Site	Columbus		
ID	COL01-SWB		
Approach	Southwestbound		
Intersection	Blackmon Rd./Warm Springs Rd.		
County	Muscogee		
City	Columbus		
GDOT District	3		
AADT	n/a		
Date of data collection	Friday, November 02, 2012		
Time of data collection	3:50 PM – 5:57 PM		
Video duration	2:07:00		
Queuing periods at least 1 minute long	3		
Total number of queued minutes	3		
	Total data	vph data	
Number of entering vehicles	914	432	
Number of circulating vehicles	352	167	
Number of exiting vehicles	746	353	

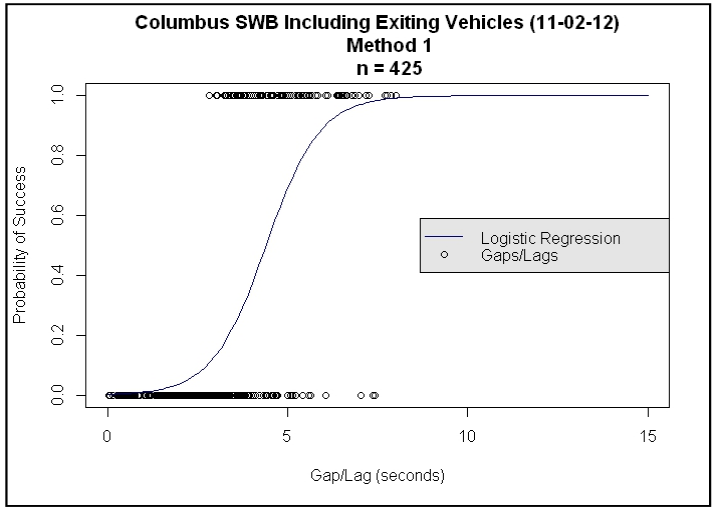
Source: Google Earth™, accessed 8/16/2013

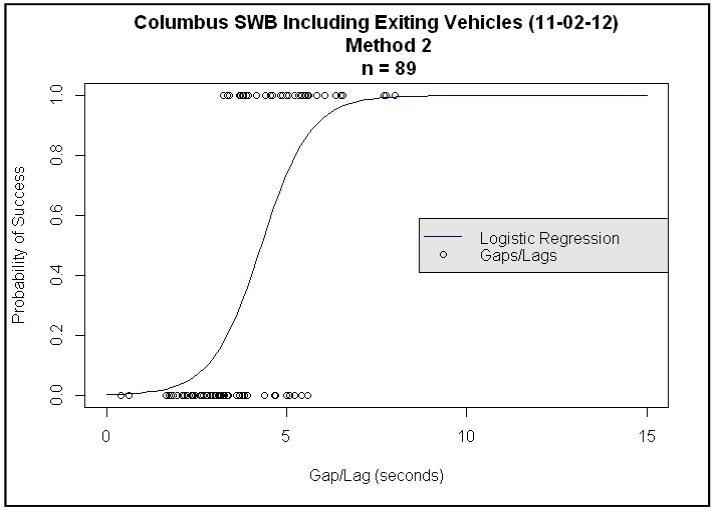
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	5.556 (2.3)	115	4.862 (3.6)	310	3.055 (1.1)	89	2.191 (1.2)	221
Excluding exiting vehicles	8.161 (4.6)	25	7.532 (6.4)	130	2.630 (0.7)	27	2.090 (1.6)	105

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	3.119 (0.7)	12	3.6	2.934 (0.7)	264
Excluding exiting vehicles	3.556 (1.3)	22	4.0	3.380 (1.1)	397

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.404 (1.8)	425	4.297 (1.7)	89	4.208 (1.1)	5
Excluding exiting vehicles	5.414 (2.0)	157	3.781 (2.1)	17	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





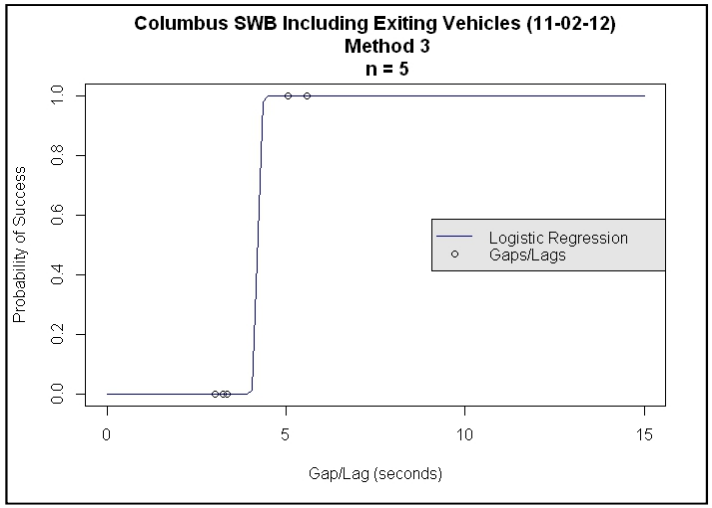
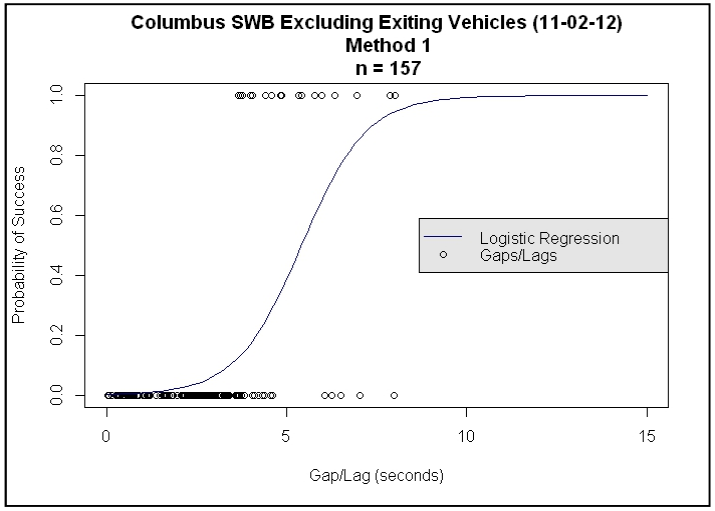


Figure 57. Critical headway including exiting vehicles for Columbus southwestbound approach



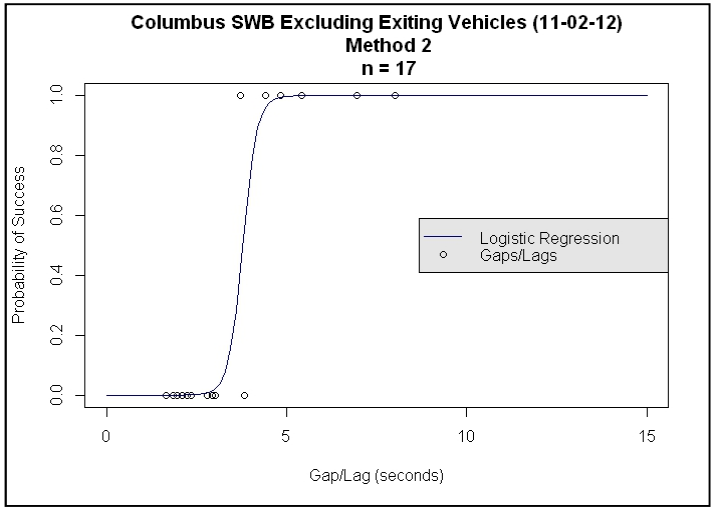


Figure 58. Critical headway excluding exiting vehicles for Columbus southwestbound approach

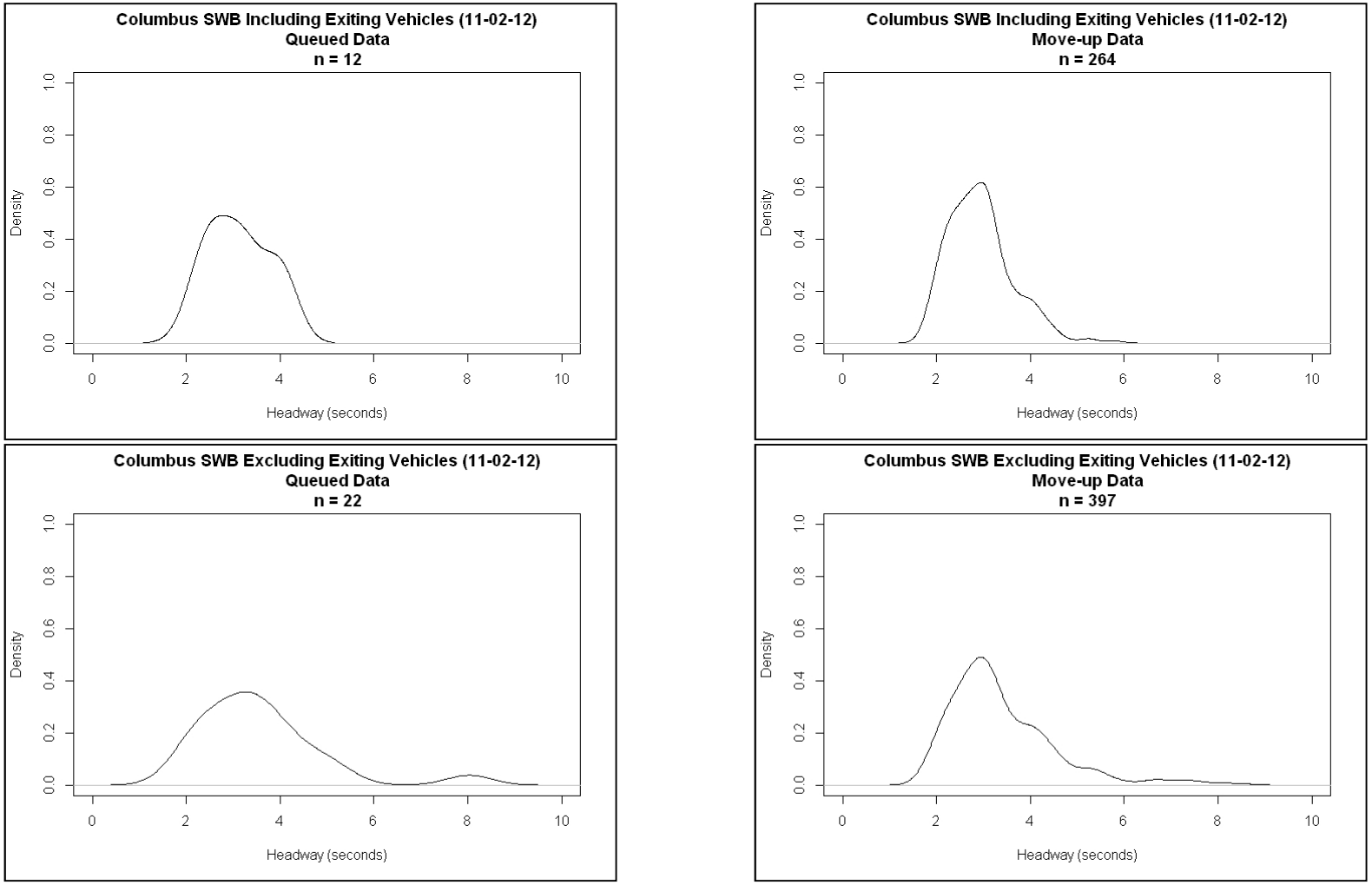


Figure 59. Follow-up headway for Columbus southwestbound approach

Table 29. Data summary sheet for Douglasville eastbound approach

Site	Douglasville		
ID	DOU01-EB		
Approach	Eastbound		
Intersection	Duncan Memorial Hwy. (SR 166)/Bill Arp Rd. (SR 5)		
County	Douglas		
City	Douglasville		
GDOT District	7		
AADT	7660		
Date of data collection	Monday, May 14, 2012		
Time of data collection	4:37 PM – 6:54PM		
Video duration	2:17:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	482	212	
Number of circulating vehicles	450	198	
Number of exiting vehicles	915	401	

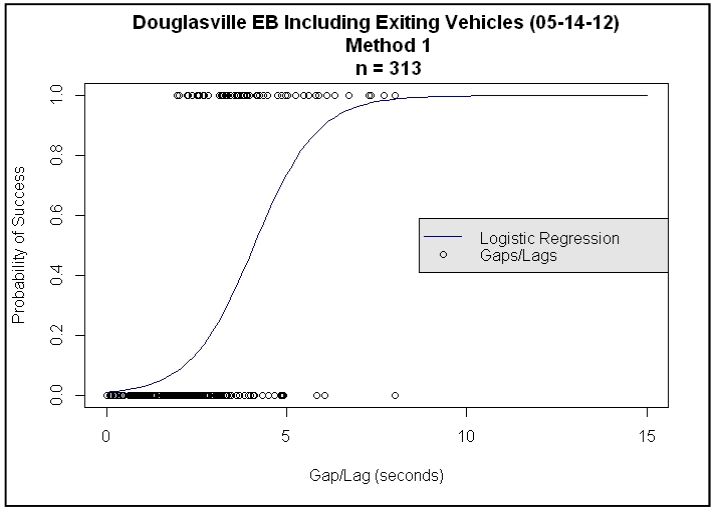
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.610 (5.8)	82	5.904 (4.8)	149	2.629 (1.3)	92	1.823 (1.0)	139
Excluding exiting vehicles	12.359 (6.2)	19	11.866 (10.2)	143	2.639 (1.0)	34	2.397 (1.9)	78

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.743 (0.7)	89
Excluding exiting vehicles	n/a (n/a)	0	4.0	2.810 (0.7)	94

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.096 (1.9)	313	3.520 (1.7)	78	n/a (n/a)	0
Excluding exiting vehicles	6.367 (2.3)	131	4.876 (2.6)	12	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



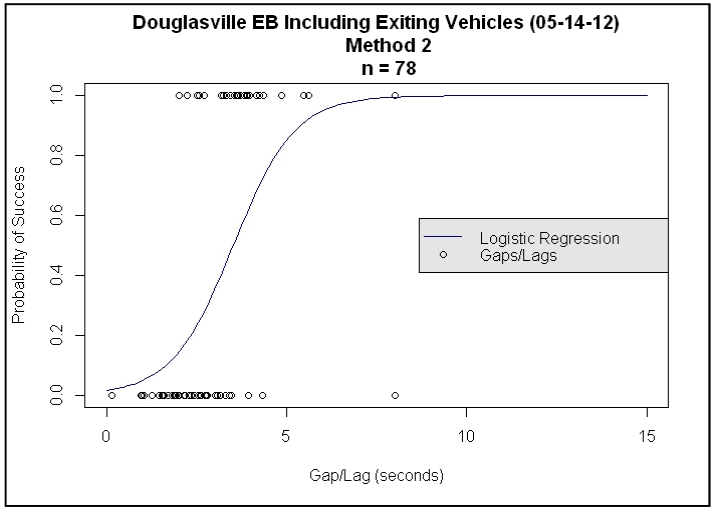
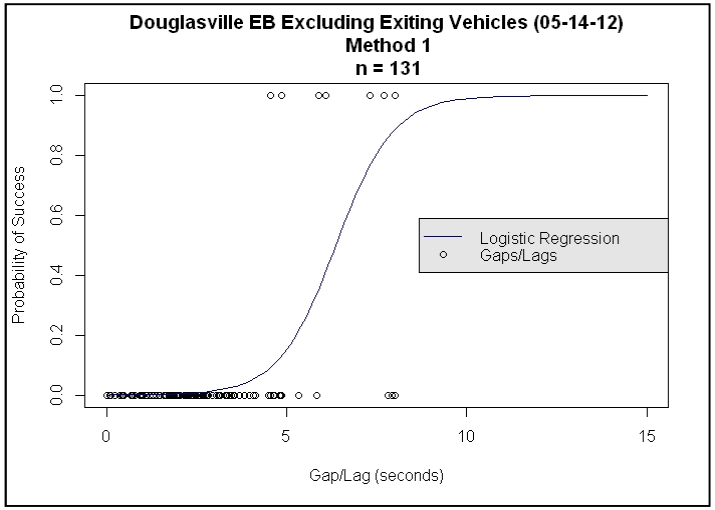


Figure 60. Critical headway including exiting vehicles for Douglasville eastbound approach



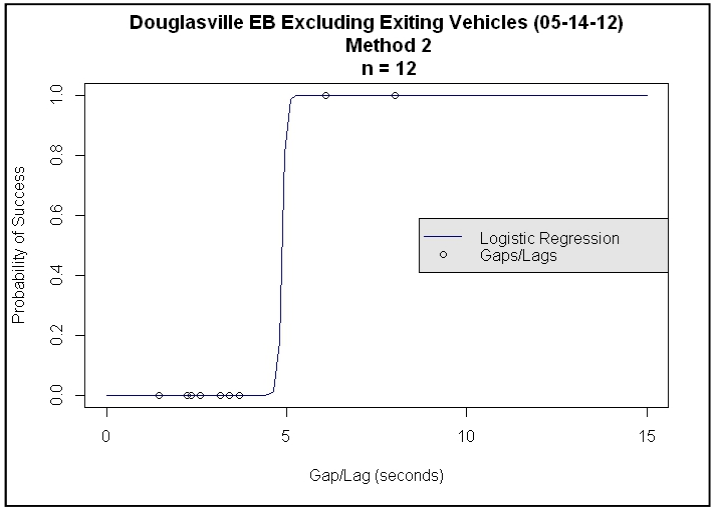


Figure 61. Critical headway excluding exiting vehicles for Douglasville eastbound approach

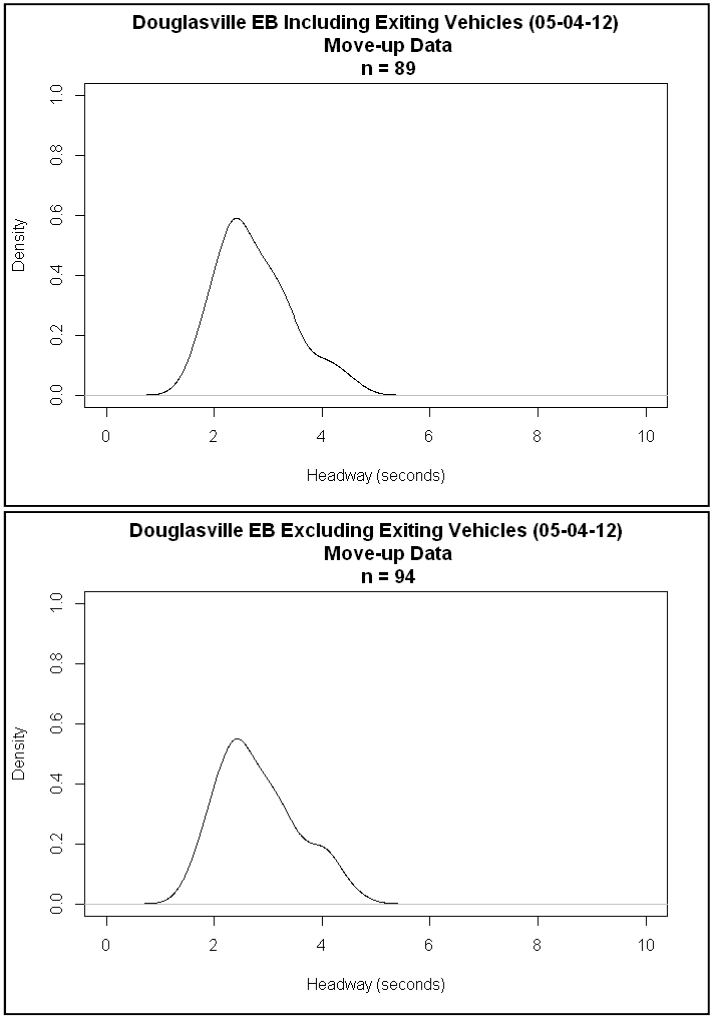


Figure 62. Follow-up headway for Douglasville eastbound approach

Table 30. Data summary sheet for Douglasville westbound approach

Site	Douglasville		
ID	DOU01-WB		
Approach	Westbound		
Intersection	Duncan Memorial Hwy. (SR 166)/Bill Arp Rd. (SR 5)		
County	Douglas		
City	Douglasville		
GDOT District	7		
AADT	7660		
Date of data collection	Monday, May 14, 2012		
Time of data collection	4:30 PM – 6:40PM		
Video duration	2:10:00		
Queuing periods at least 1 minute long	1		
Total number of queued minutes	1		
	Total data	vph data	
Number of entering vehicles	734	339	
Number of circulating vehicles	451	209	
Number of exiting vehicles	292	135	

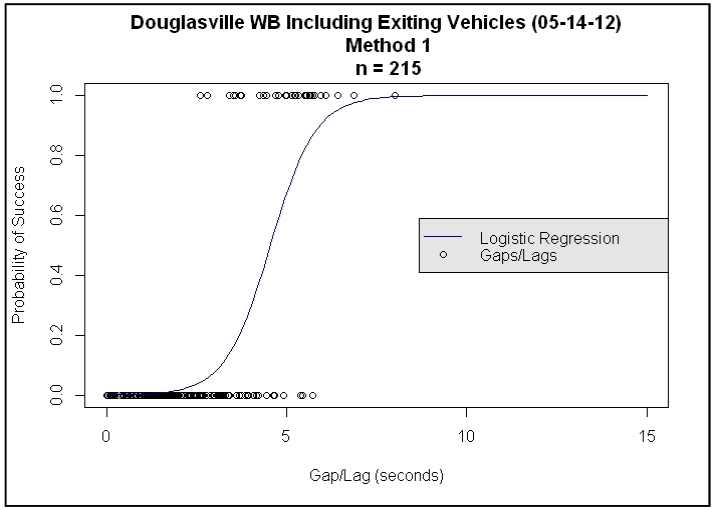
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	7.082 (5.2)	36	7.854 (6.2)	226	2.457 (1.1)	58	1.617 (1.1)	121
Excluding exiting vehicles	10.855 (7.3)	15	10.953 (8.4)	167	2.637 (1.1)	43	1.591 (1.1)	107

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	3.167 (0.7)	11	3.6	2.708 (0.7)	217
Excluding exiting vehicles	3.481 (0.9)	16	4.0	2.931 (0.8)	258

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.549 (1.8)	215	3.974 (1.9)	29	n/a (n/a)	0
Excluding exiting vehicles	5.290 (1.8)	162	4.980 (2.0)	10	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



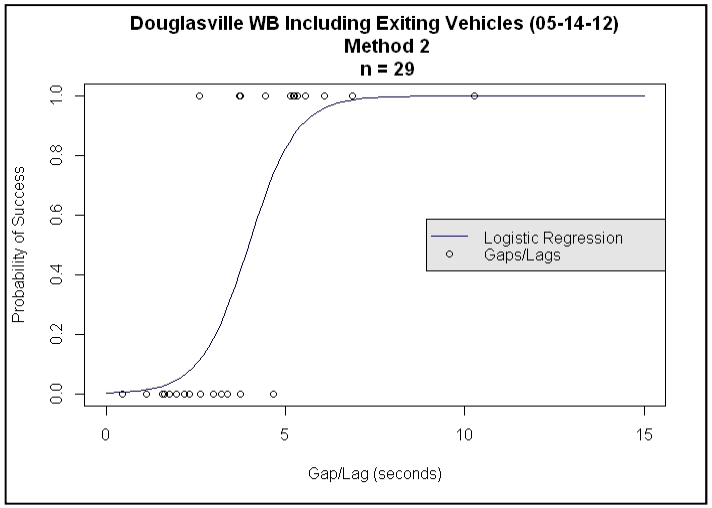
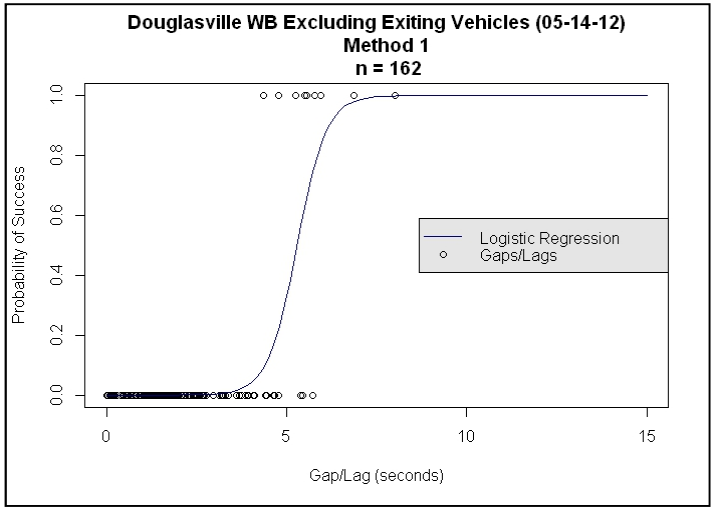


Figure 63. Critical headway including exiting vehicles for Douglasville westbound approach



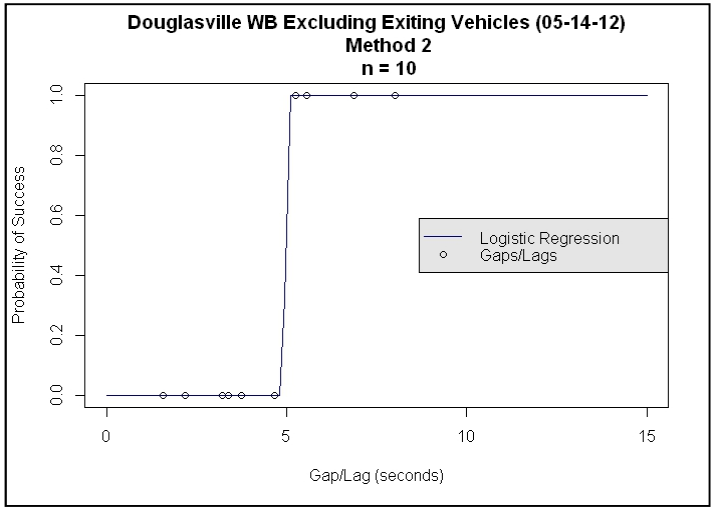


Figure 64. Critical headway excluding exiting vehicles for Douglasville westbound approach

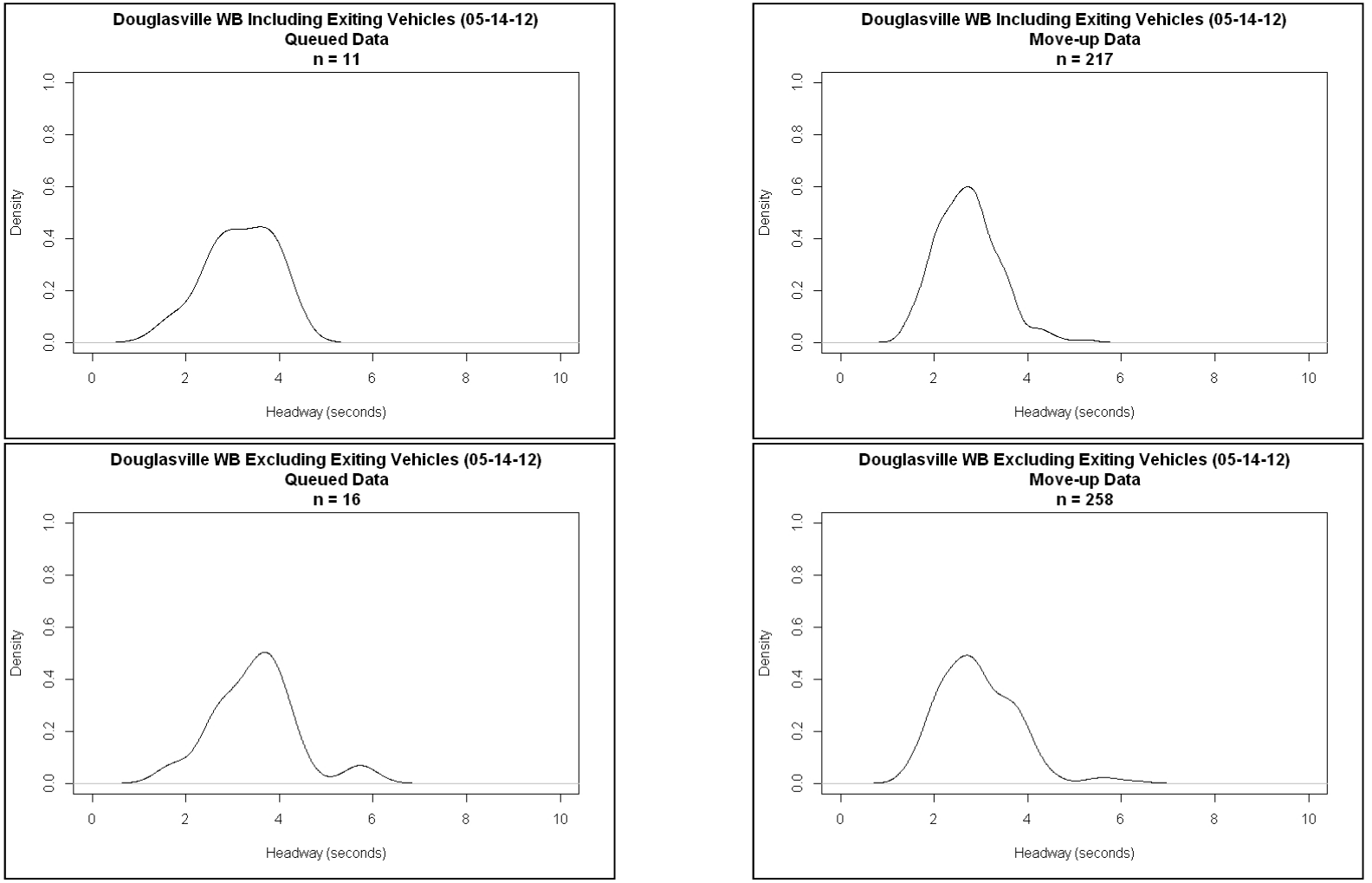


Figure 65. Follow-up headway for Douglasville westbound approach

Table 31. Data summary sheet for Douglasville southbound approach

Site	Douglasville		
ID	DOU01-SB		
Approach	Southbound		
Intersection	Duncan Memorial Hwy. (SR 166)/Bill Arp Rd. (SR 5)		
County	Douglas		
City	Douglasville		
GDOT District	7		
AADT	7660		
Date of data collection	Tuesday, November 1, 2012		
Time of data collection	7:05 AM – 8:32 AM		
Video duration	1:27:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	200	138	
Number of circulating vehicles	216	149	
Number of exiting vehicles	343	237	

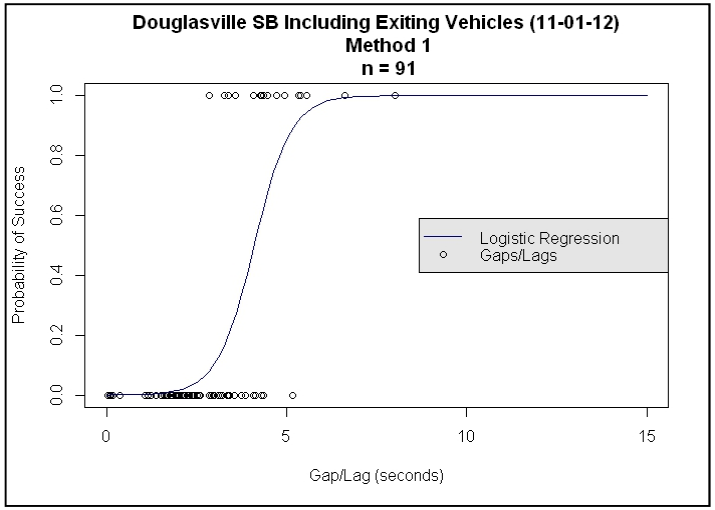
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	8.609 (5.9)	28	8.847 (7.7)	93	2.723 (0.8)	17	2.070 (1.1)	46
Excluding exiting vehicles	17.500 (14.2)	8	16.467 (15.4)	68	3.098 (2.0)	5	2.003 (1.8)	21

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.689 (1.0)	45
Excluding exiting vehicles	n/a (n/a)	0	4.0	3.108 (1.1)	54

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.010 (2.2)	91	3.733 (1.6)	18	n/a (n/a)	0
Excluding exiting vehicles	6.023 (2.7)	34	n/a (n/a)	0	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



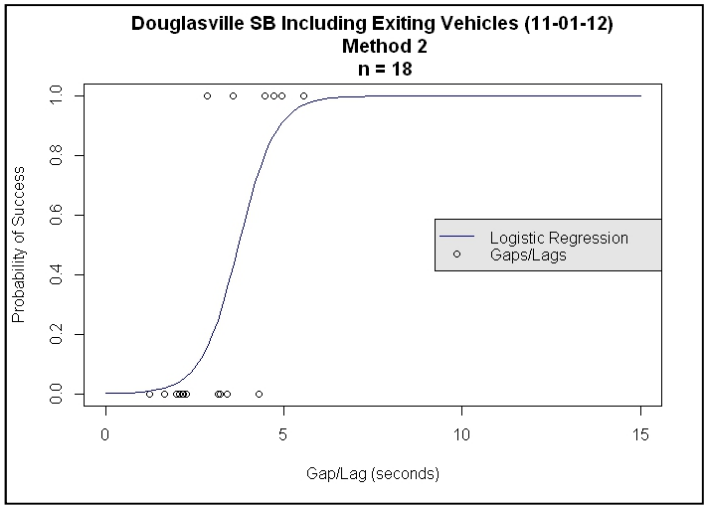


Figure 66. Critical headway including exiting vehicles for Dougalsville southbound approach

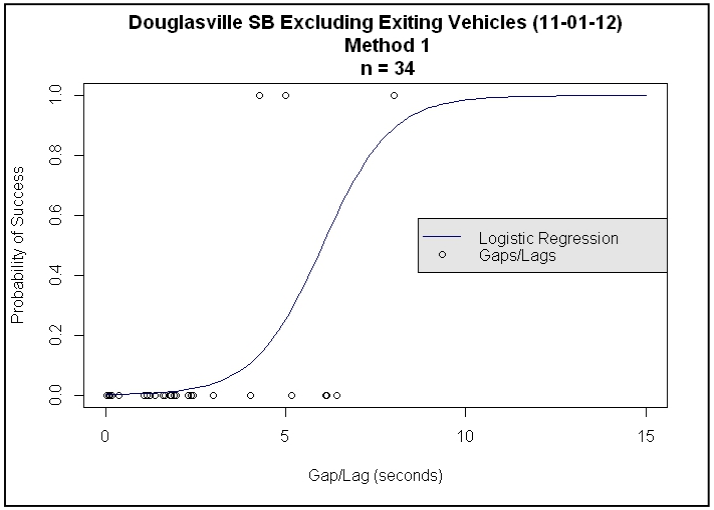


Figure 67. Critical headway excluding exiting vehicles for Dougalsville southbound approach

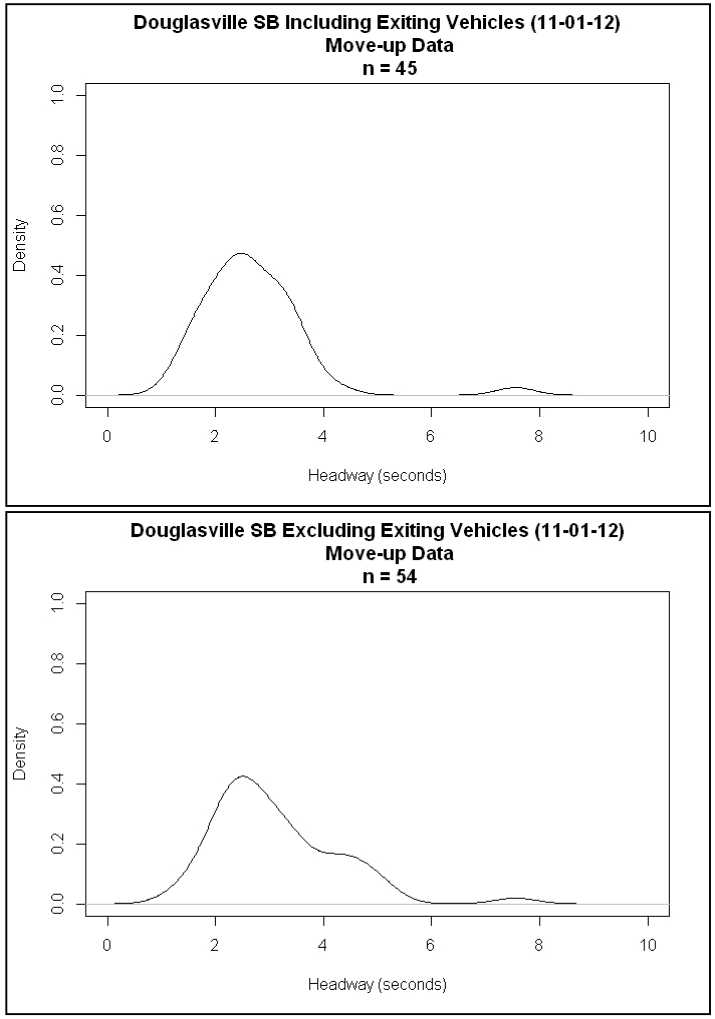


Figure 68. Follow-up headway for Dougalsville southbound approach

Table 32. Data summary sheet for Emory southeastbound approach

Site	Emory		
ID	EMO01-SEB		
Approach	Southeastbound		
Intersection	N. Decatur Rd./Oxford Rd. NE		
County	Dekalb		
City	Atlanta		
GDOT District	7		
AADT	n/a		
Date of data collection	Friday, October 19, 2012		
Time of data collection	4:10 PM – 5:59 PM		
Video duration	1:49:00		
Queuing periods at least 1 minute long	18		
Total number of queued minutes	32		
	Total data	vph data	
Number of entering vehicles	524	291	
Number of circulating vehicles	1371	755	
Number of exiting vehicles	314	173	

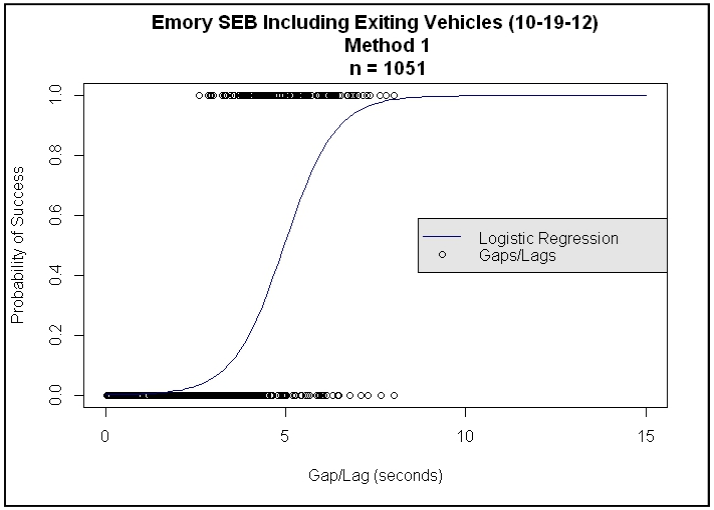
Source: Google Earth™, accessed 8/16/2013

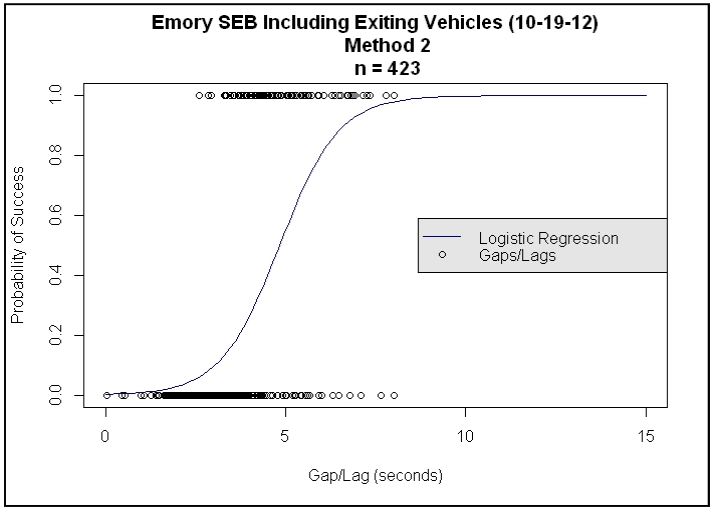
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	5.643 (2.7)	160	5.119 (3.5)	107	2.908 (1.0)	604	1.890 (1.2)	287
Excluding exiting vehicles	6.595 (3.0)	117	5.842 (4.3)	95	3.012 (1.2)	496	1.942 (1.4)	264

Follow-up Headway	**Queued Data**		**Move-up Data**			
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n	
Including exiting vehicles	3.680 (1.4)	70	3.6	3.235 (0.6)	101	
Excluding exiting vehicles	3.897 (1.5)	85	4.0	3.512 (0.9)	133	

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.961 (1.5)	1051	4.834 (1.4)	423	5.241 (1.4)	224
Excluding exiting vehicles	5.555 (1.7)	877	5.175 (1.7)	284	5.134 (1.5)	157

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





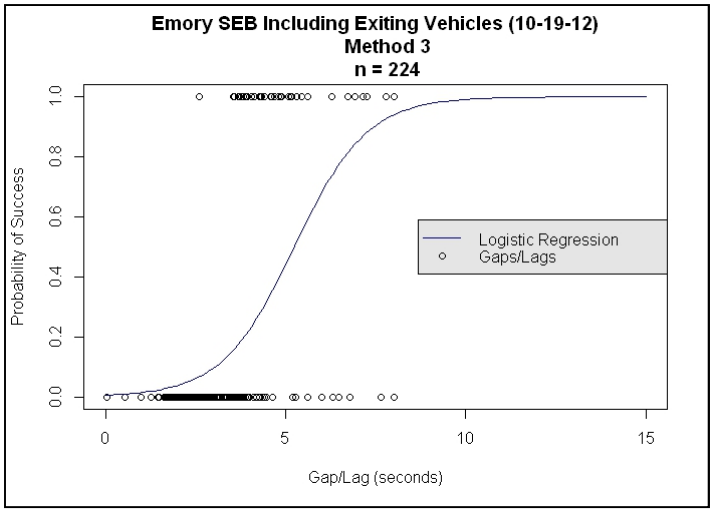
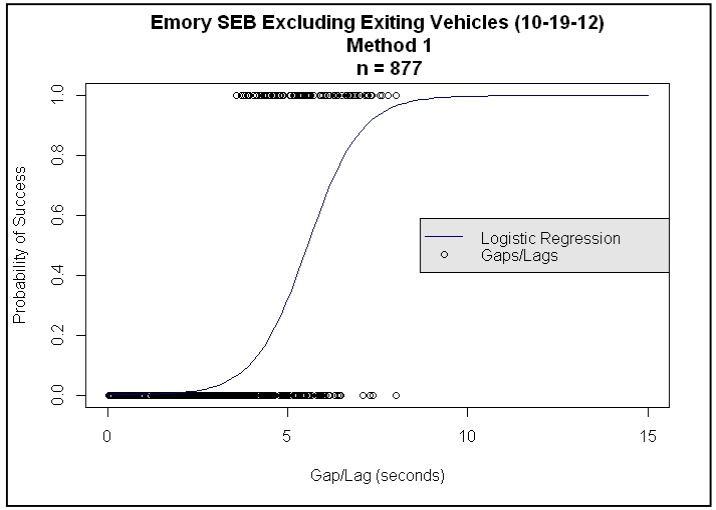
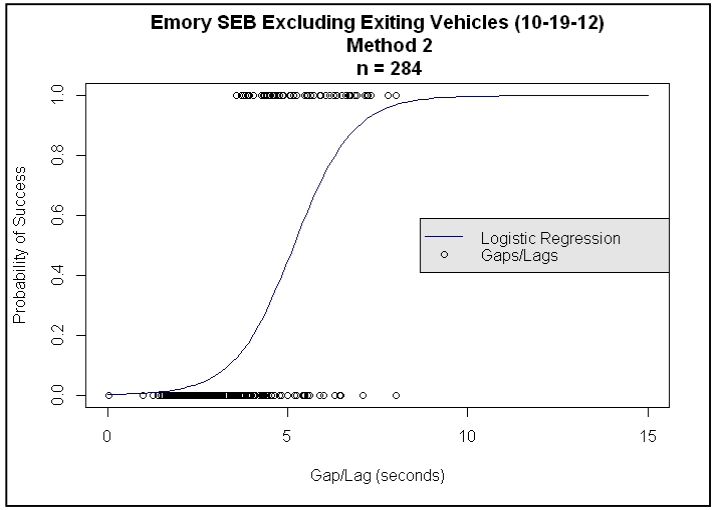


Figure 69. Critical headway including exiting vehicles for Emory southeastbound approach





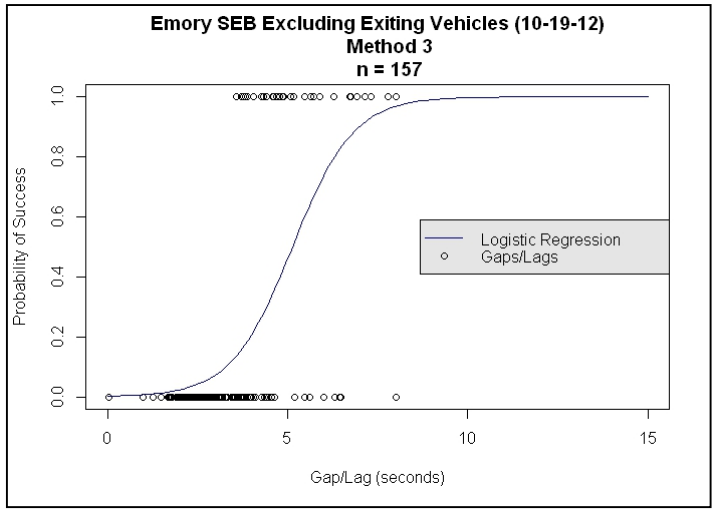


Figure 70. Critical headway excluding exiting vehicles for Emory southeastbound approach

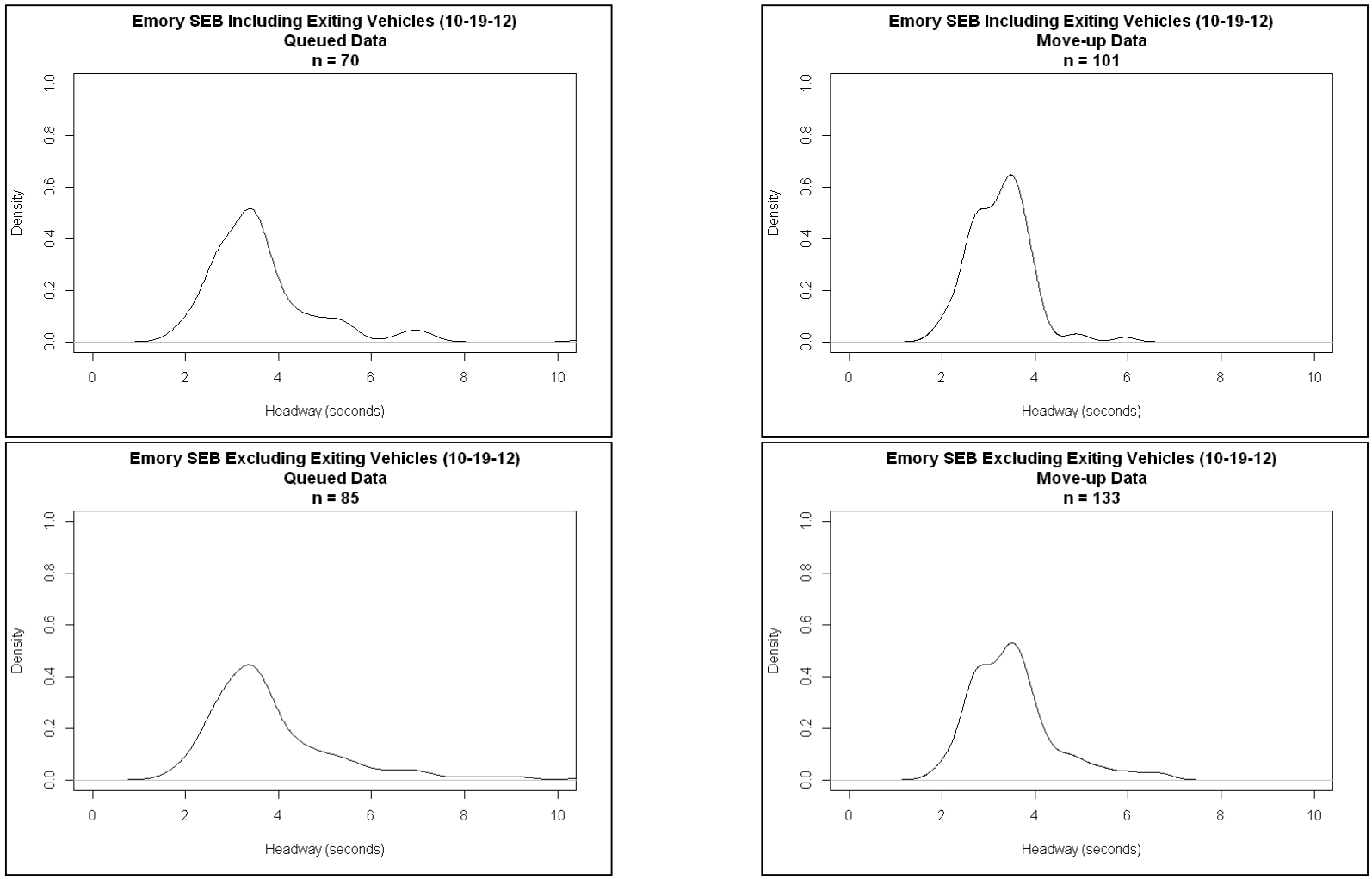


Figure 71. Follow-up headway for Emory southeastbound approach

Table 33. Data summary sheet for Fayetteville eastbound approach

Site	Fayetteville		
ID	FAY01-EB		
Approach	Eastbound		
Intersection	Grady Ave./Beauregard Blvd.		
County	Fayette		
City	Fayetteville		
GDOT District	3		
AADT	7920		
Date of data collection	Wednesday, April 11, 2012		
Time of data collection	4:37 PM – 6:49 PM		
Video duration	2:12:00		
Queuing periods at least 1 minute long	3		
Total number of queued minutes	3		
	Total data	vph data	
Number of entering vehicles	693	315	
Number of circulating vehicles	592	270	
Number of exiting vehicles	641	292	

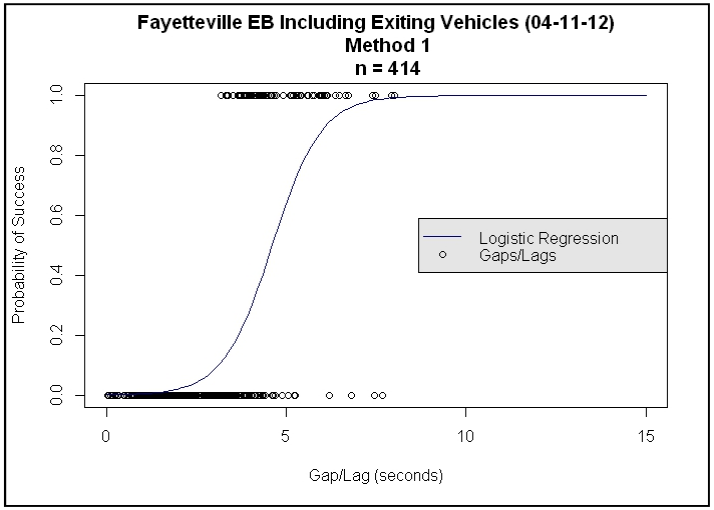
Source: Google Earth™, accessed 8/16/2013

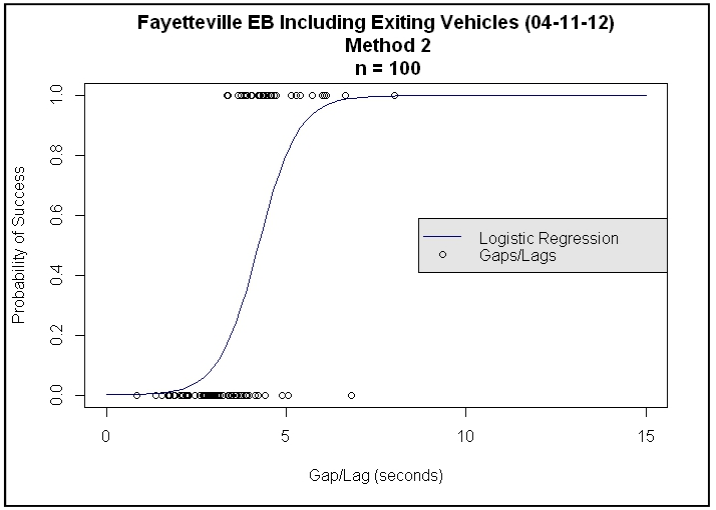
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	7.814 (8.2)	262	5.300 (4.4)	262	2.980 (1.0)	143	1.885 (1.1)	182
Excluding exiting vehicles	8.505 (4.3)	36	8.237 (8.9)	155	3.022 (1.4)	86	1.963 (1.8)	124

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.840 (1.1)	17	3.6	2.969 (1.0)	188
Excluding exiting vehicles	3.226 (1.5)	24	4.0	3.259 (1.3)	259

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.613 (1.9)	414	4.230 (1.6)	100	3.956 (0.7)	16
Excluding exiting vehicles	6.108 (2.2)	246	4.938 (2.4)	33	3.814 (0.9)	7

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





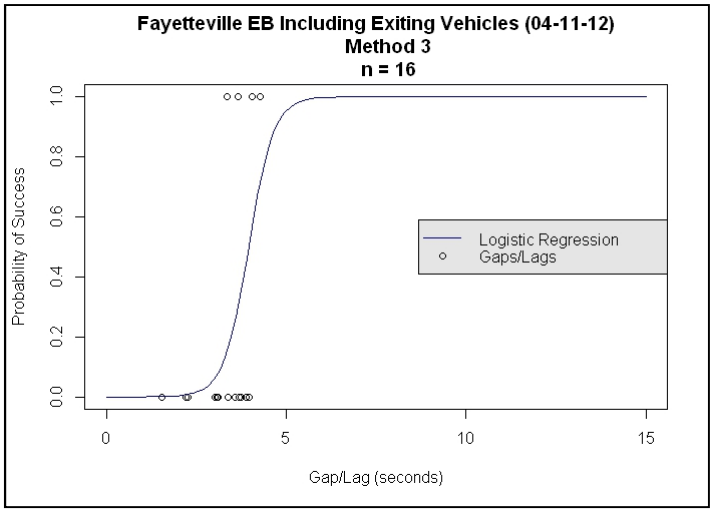
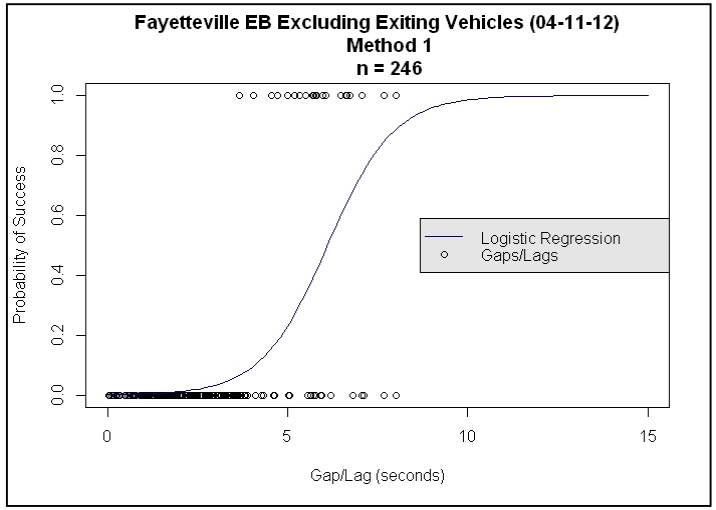
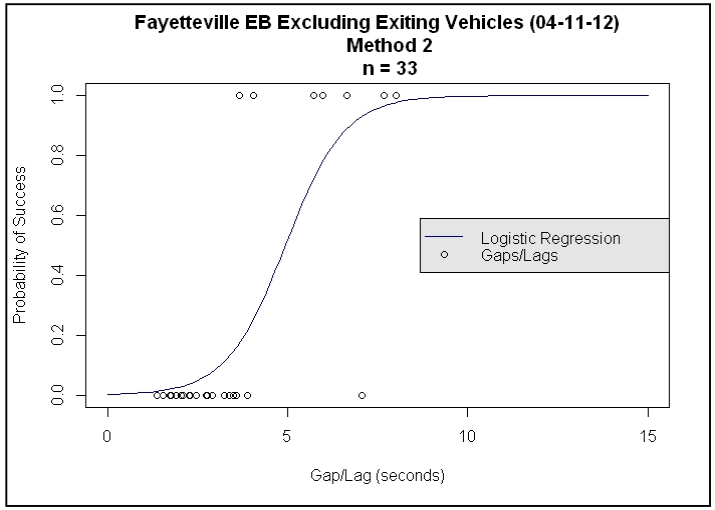


Figure 72. Critical headway including exiting vehicles for Fayetteville eastbound approach





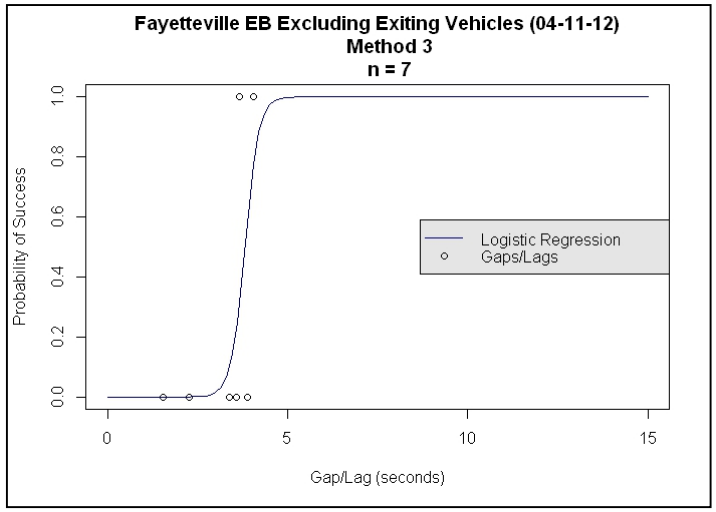


Figure 73. Critical headway excluding exiting vehicles for Fayetteville eastbound approach

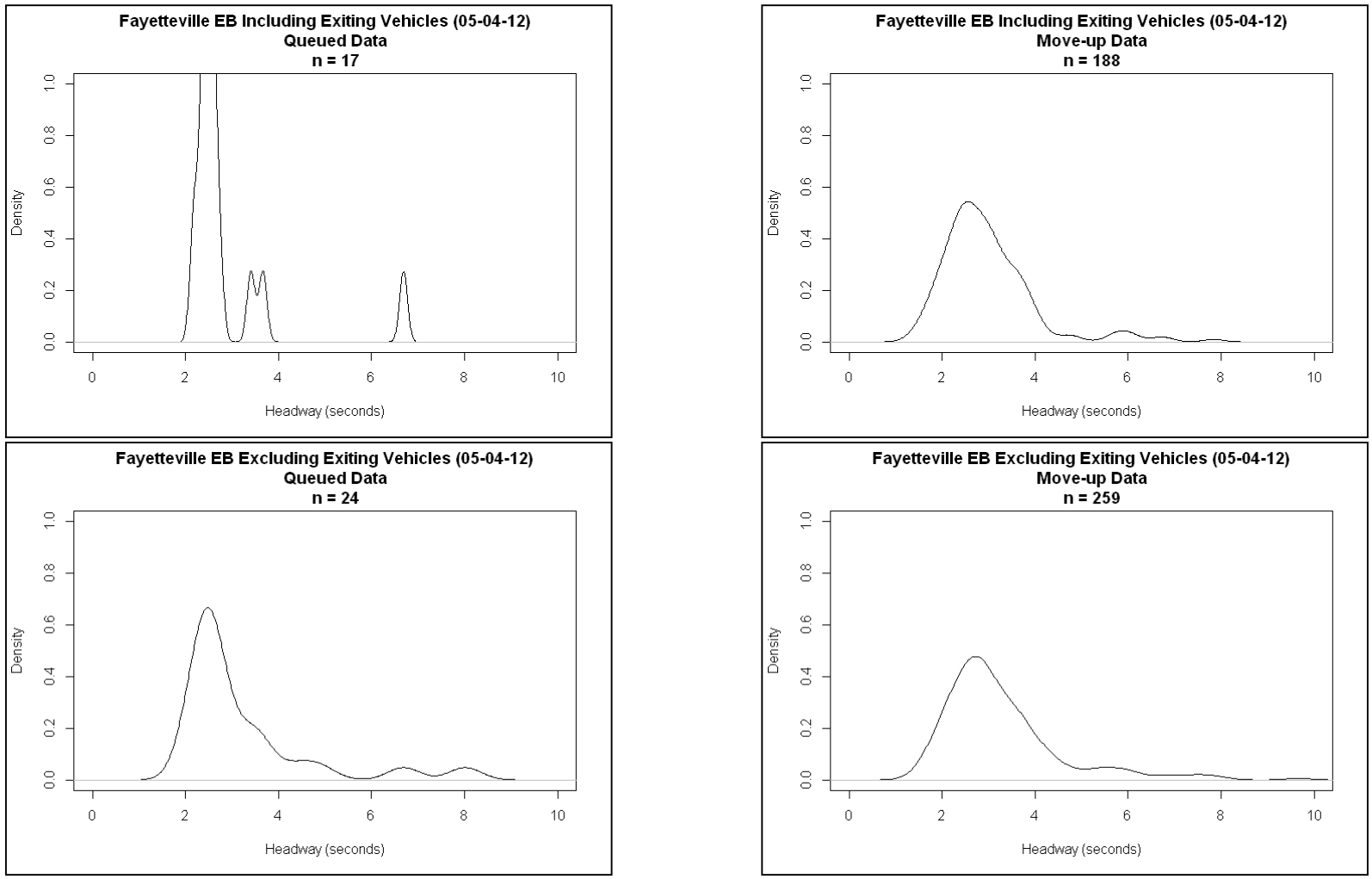


Figure 74. Follow-up headway for Fayetteville eastbound approach

Table 34. Data summary sheet for Fayetteville southbound approach

Site	Fayetteville		
ID	FAY01-SB		
Approach	Southbound		
Intersection	Grady Ave./Beauregard Blvd.		
County	Fayette		
City	Fayetteville		
GDOT District	3		
AADT	6650		
Date of data collection	Wednesday, April 11, 2012		
Time of data collection	4:31 PM – 6:33 PM		
Video duration	2:02:00		
Queuing periods at least 1 minute long	3		
Total number of queued minutes	3		
	Total data	vph data	
Number of entering vehicles	590	291	
Number of circulating vehicles	572	282	
Number of exiting vehicles	199	98	

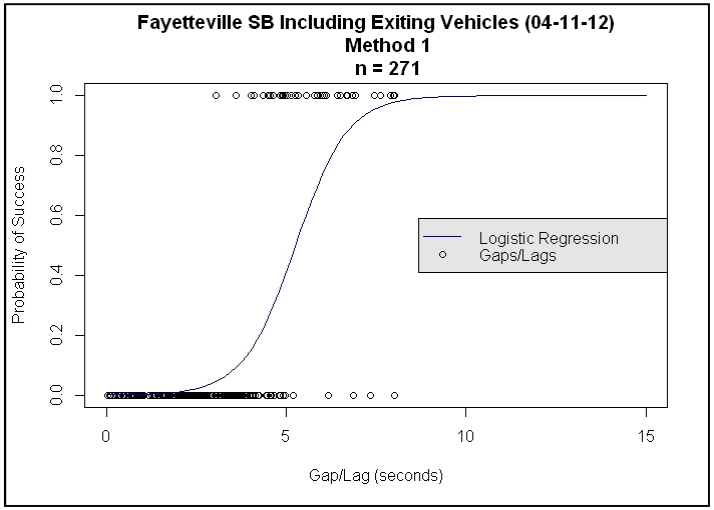
Source: Google Earth™, accessed 8/16/2013

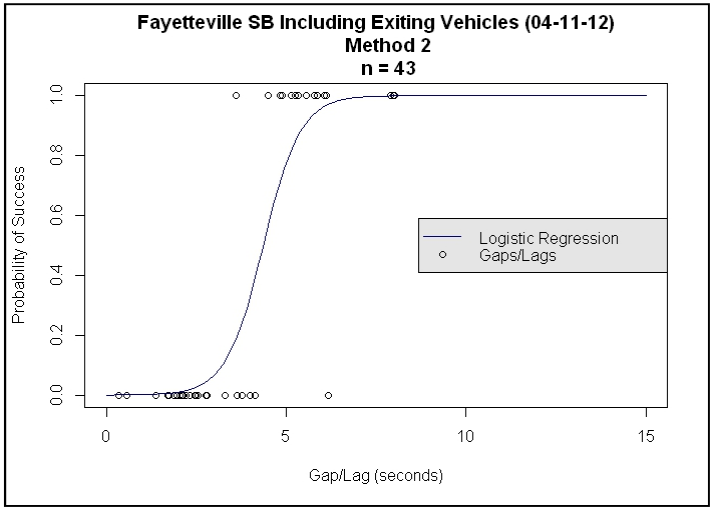
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	7.393 (3.8)	48	7.820 (8.2)	156	3.014 (1.4)	94	2.075 (1.2)	129
Excluding exiting vehicles	9.309 (6.0)	32	9.878 (9.8)	125	2.973 (1.2)	73	2.109 (1.5)	111

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	3.288 (1.9)	23	3.6	2.909 (0.9)	213
Excluding exiting vehicles	3.361 (1.8)	25	4.0	3.078 (1.0)	244

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.260 (2.0)	271	4.363 (2.2)	43	3.708 (1.8)	5
Excluding exiting vehicles	5.664 (2.0)	216	4.974 (2.3)	25	4.136 (2.0)	3

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





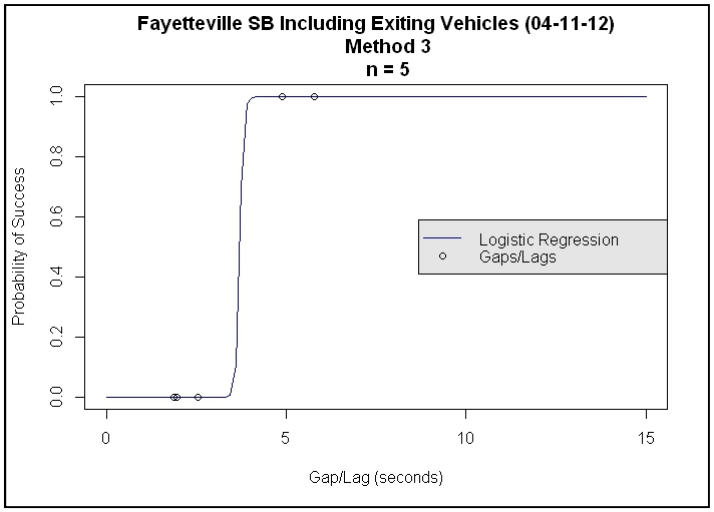
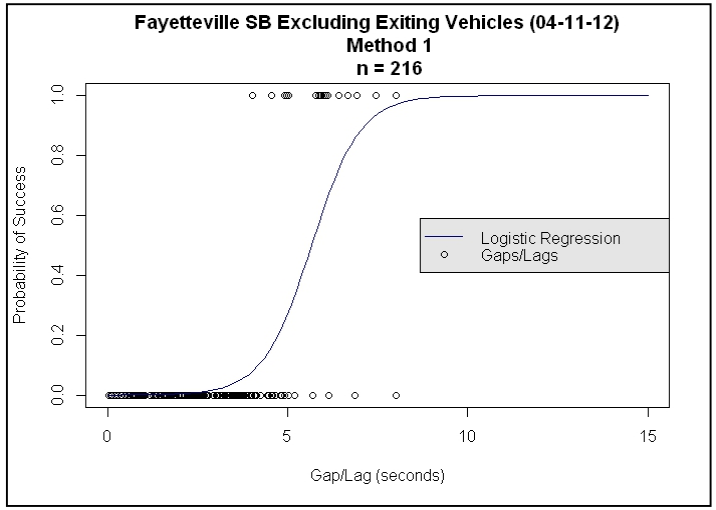
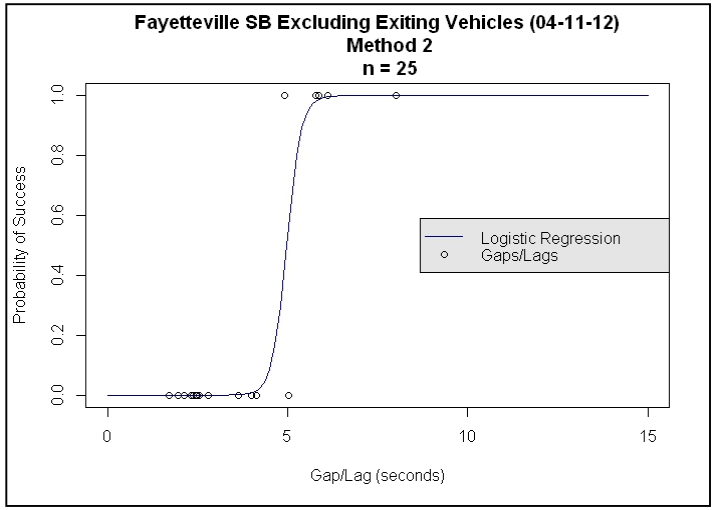


Figure 75. Critical headway including exiting vehicles for Fayetteville southbound approach





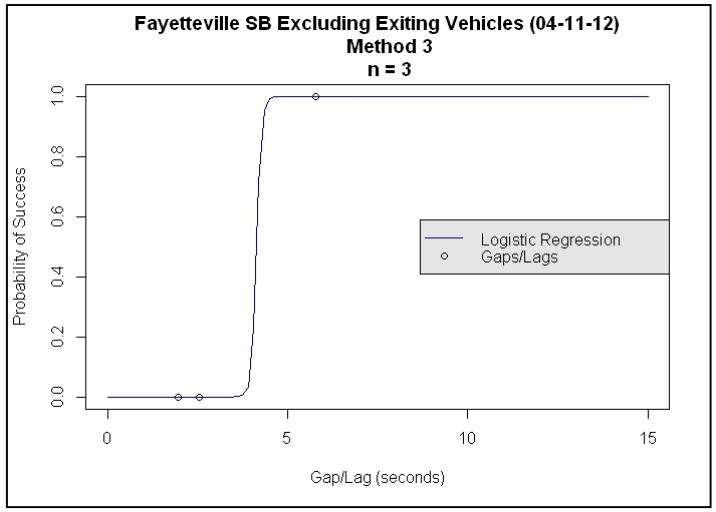


Figure 76. Critical headway excluding exiting vehicles for Fayetteville southbound approach

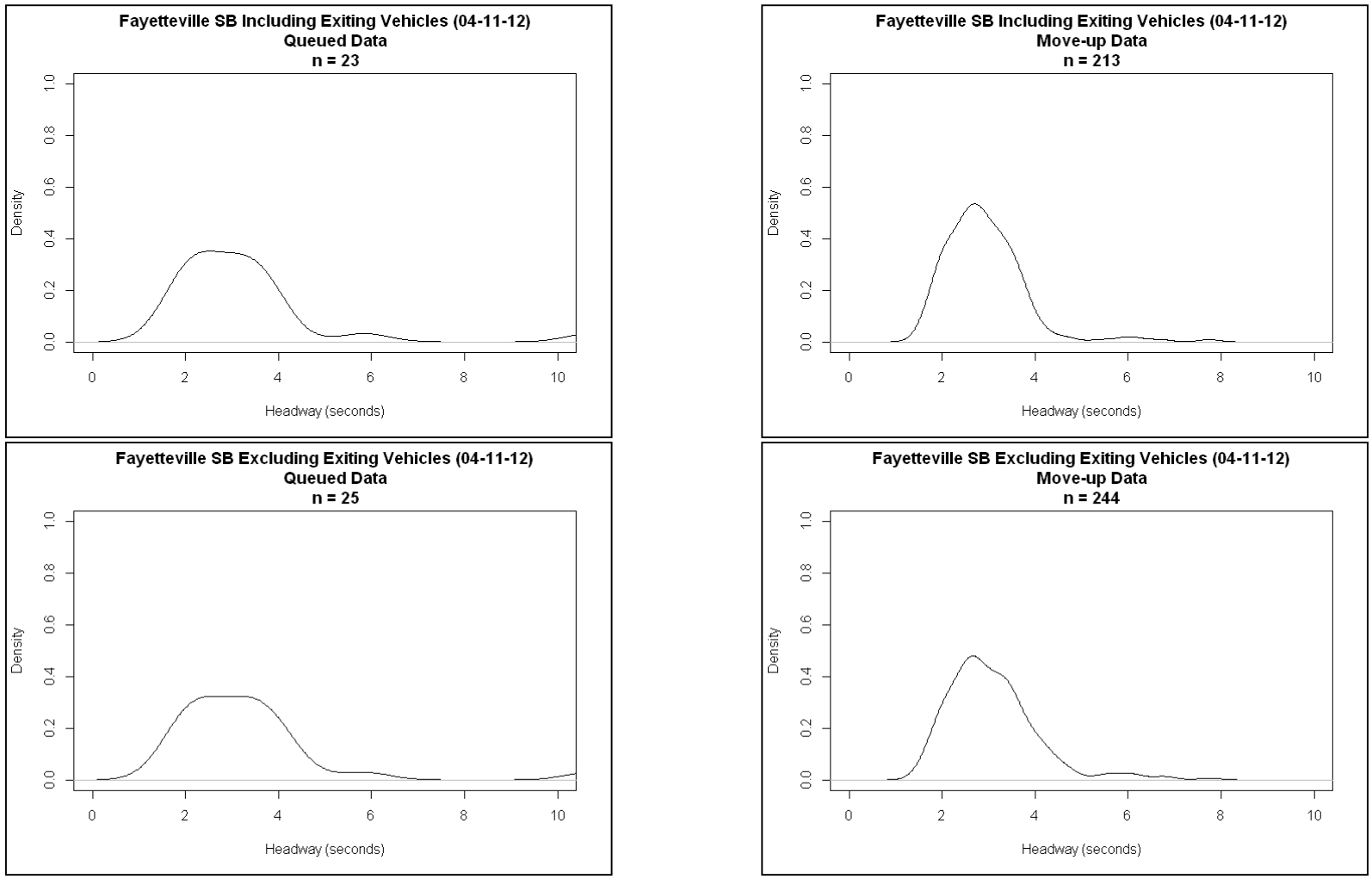


Figure 77. Follow-up headway for Fayetteville southbound approach

Table 35. Data summary sheet for Fayetteville northbound approach

Site	Fayetteville		
ID	FAY01-NB		
Approach	Northbound		
Intersection	Grady Ave./Beauregard Blvd.		
County	Fayette		
City	Fayetteville		
GDOT District	3		
AADT	6650		
Date of data collection	Wednesday, April 11, 2012		
Time of data collection	7:40 AM – 8:46 AM		
Video duration	1:06:00		
Queuing periods at least 1 minute long	2		
Total number of queued minutes	2		
	Total data	vph data	
Number of entering vehicles	712	648	
Number of circulating vehicles	537	489	
Number of exiting vehicles	772	702	

Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.315 (4.1)	102	5.421 (4.1)	283	3.034 (1.1)	139	2.101 (1.2)	196
Excluding exiting vehicles	8.486 (1.3)	25	8.420 (8.0)	148	3.064 (1.8)	79	1.755 (1.3)	117

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	4.190 (0.4)	8	3.6	3.051 (0.8)	170
Excluding exiting vehicles	4.027 (0.7)	14	4.0	3.414 (1.1)	248

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.590 (1.8)	437	4.739 (1.8)	116	7.211 (2.1)	14
Excluding exiting vehicles	6.327 (2.1)	221	5.291 (2.4)	21	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute

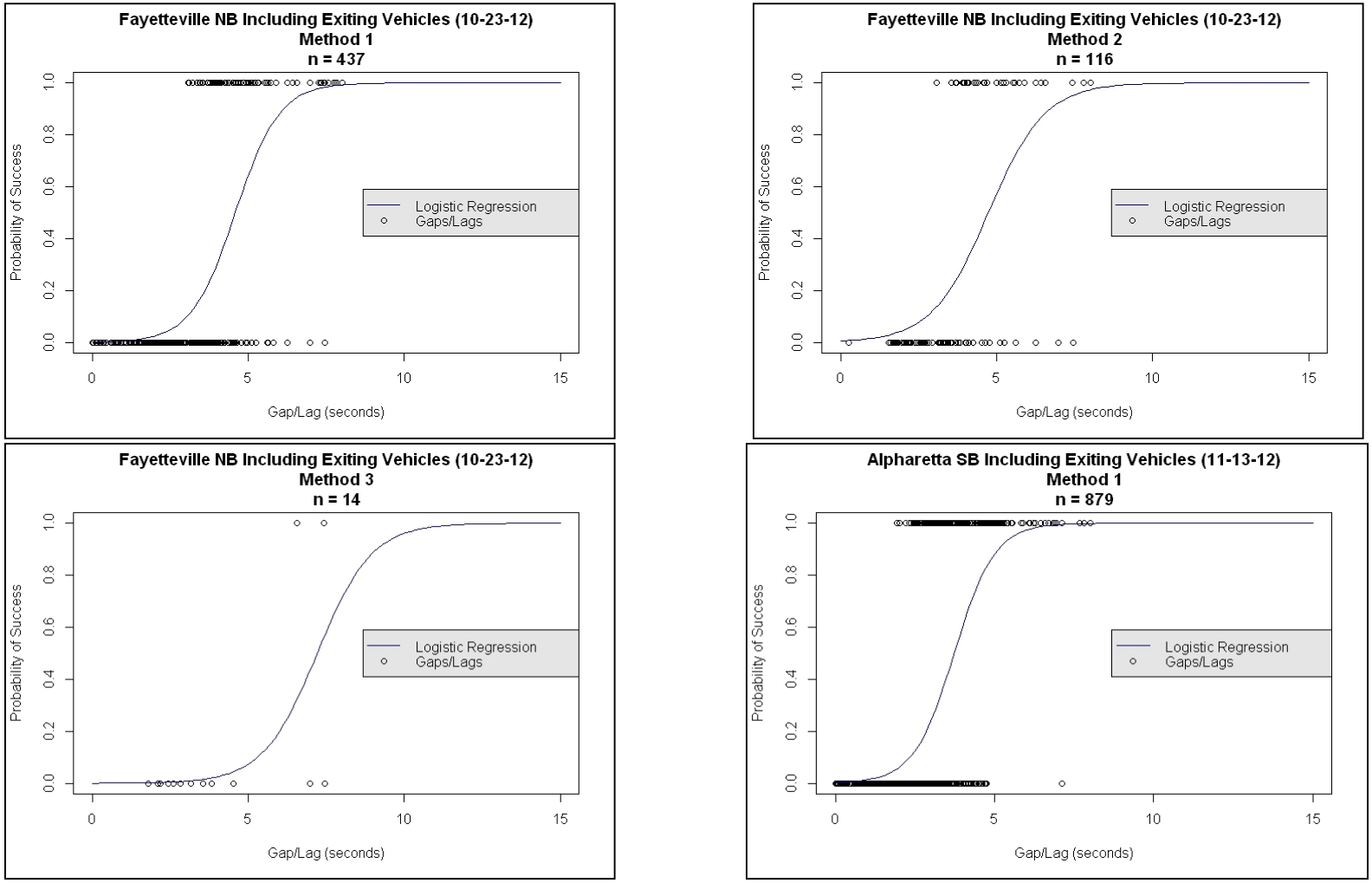
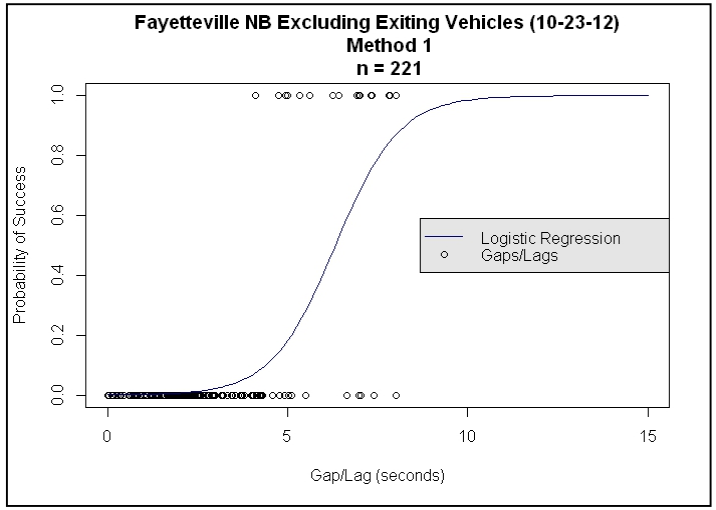


Figure 78. Critical headway including exiting vehicles for Fayetteville northbound approach



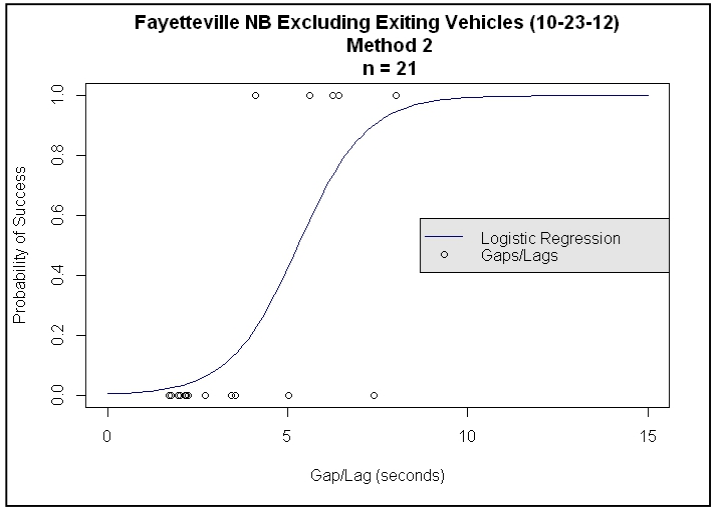


Figure 79. Critical headway excluding exiting vehicles for Fayetteville northbound approach

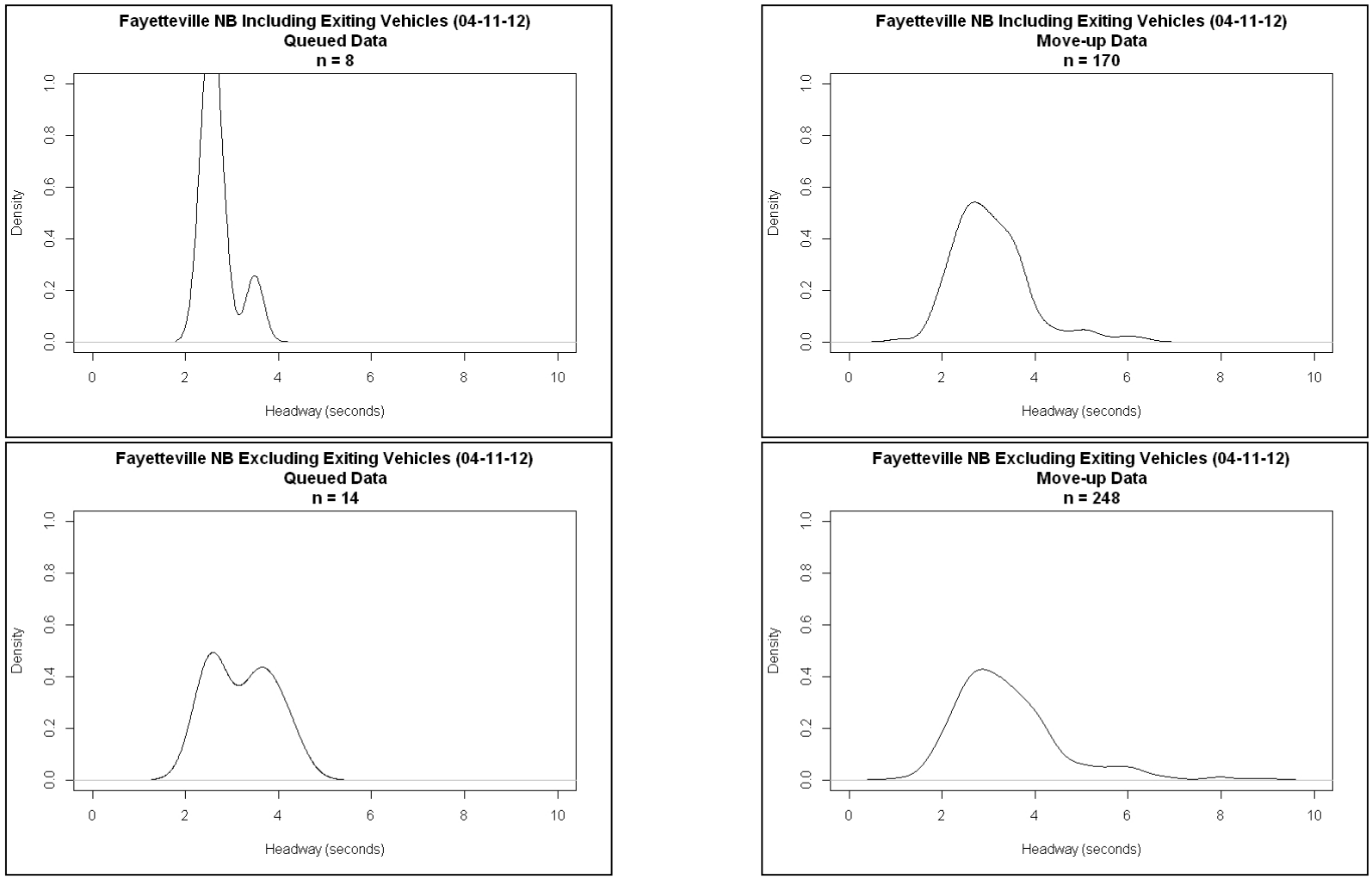


Figure 80. Follow-up headway for Fayetteville northbound approach

Table 36. Data summary sheet for Duluth eastbound approach

Site	Duluth		
ID	DUL01-EB		
Approach	Eastbound		
Intersection	McClure Bridge Rd./W. Lawrenceville St./Irvindale Rd. NW		
County	Gwinnett		
City	Duluth		
GDOT District	3		
AADT	11340		
Date of data collection	Friday, June 1, 2012		
Time of data collection	6:56 AM – 8:56 AM		
Video duration	2:00:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	455	228	
Number of circulating vehicles	71	36	
Number of exiting vehicles	697	349	

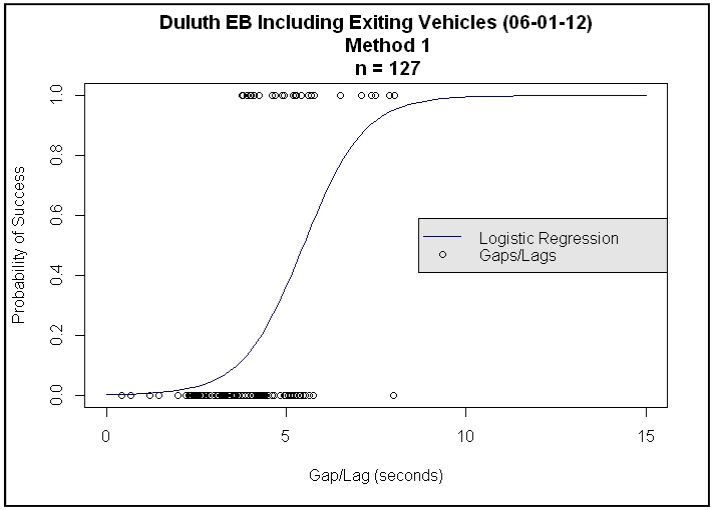
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	7.853 (4.7)	37	8.660 (6.3)	192	4.318 (0.6)	23	3.465 (1.2)	67
Excluding exiting vehicles	19.184 (n/a)	1	19.950 (17.3)	45	n/a (n/a)	0	2.648 (1.9)	12

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.780 (0.9)	107
Excluding exiting vehicles	n/a (n/a)	0	4.0	3.088 (1.0)	146

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.478 (1.7)	127	5.322 (1.3)	18	n/a (n/a)	0
Excluding exiting vehicles	7.852 (2.3)	13	n/a (n/a)	0	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



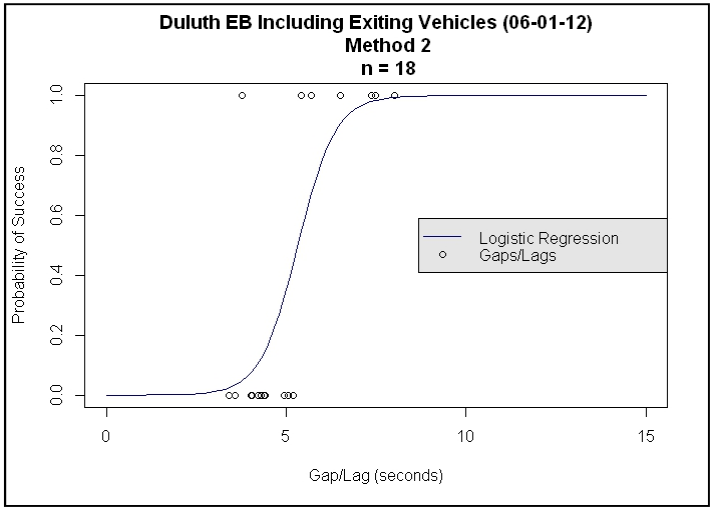


Figure 81. Critical headway including exiting vehicles for Duluth eastbound approach

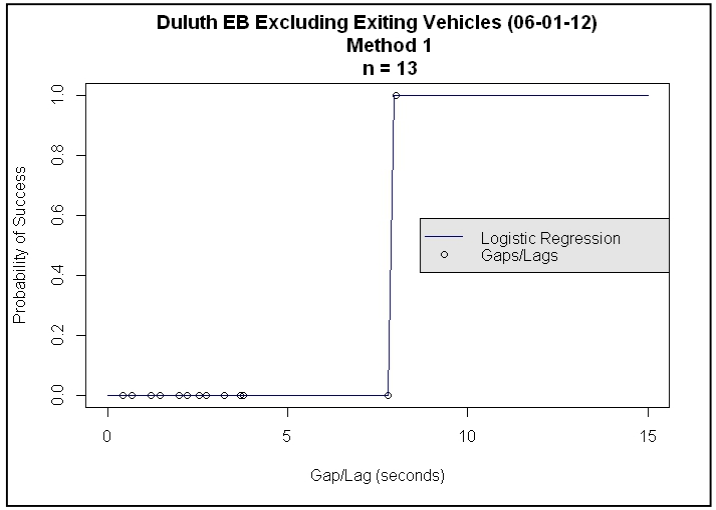


Figure 82. Critical headway excluding exiting vehicles for Duluth eastbound approach

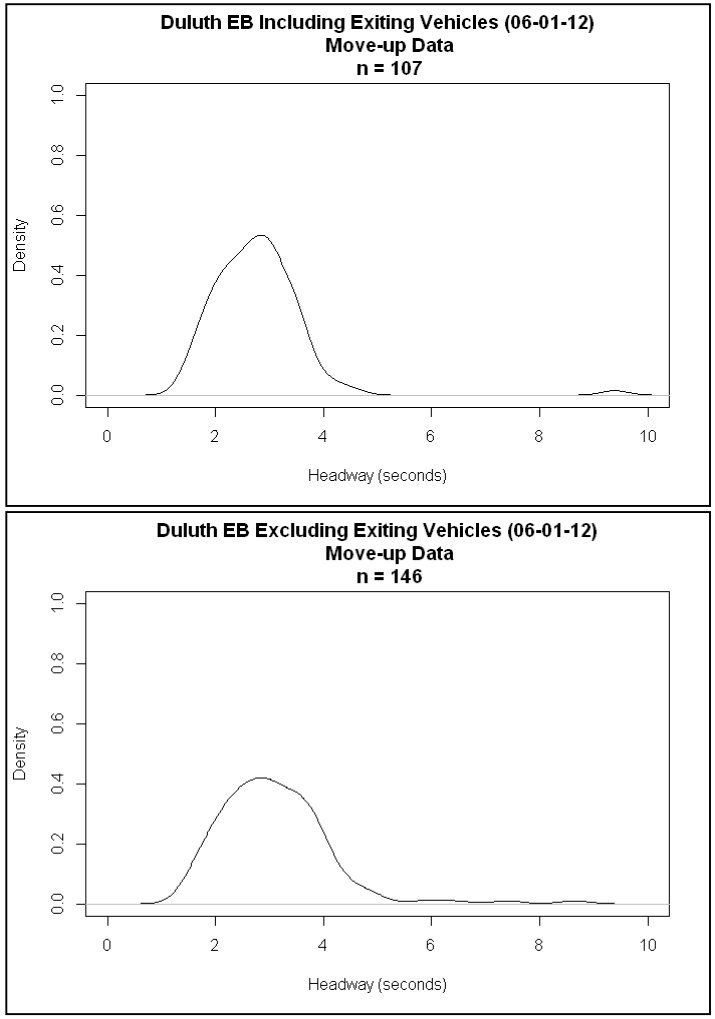


Figure 83. Follow-up headway for Duluth eastbound approach

Table 37. Data summary sheet for Hinesville westbound approach

Site	Hinesville		
ID	HIN01-WB		
Approach	Westbound		
Intersection	Memorial Dr./N. Main St.		
County	Liberty		
City	Hinesville		
GDOT District	5		
AADT	2030		
Date of data collection	Friday, July 27, 2012		
Time of data collection	3:30 PM – 4:41 PM		
Video duration	1:11:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	442	374	
Number of circulating vehicles	234	198	
Number of exiting vehicles	148	126	

Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	9.335 (7.4)	19	12.036 (8.8)	61	3.085 (1.0)	20	2.602 (1.5)	32
Excluding exiting vehicles	13.605 (8.3)	13	16.584 (12.6)	51	3.140 (1.1)	11	2.752 (1.9)	27

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	3.120 (0.4)	10
Excluding exiting vehicles	n/a (n/a)	0	4.0	3.635 (0.9)	18

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.149 (2.1)	71	3.957 (2.2)	21	n/a (n/a)	0
Excluding exiting vehicles	6.204 (2.5)	51	5.244 (2.5)	13	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute

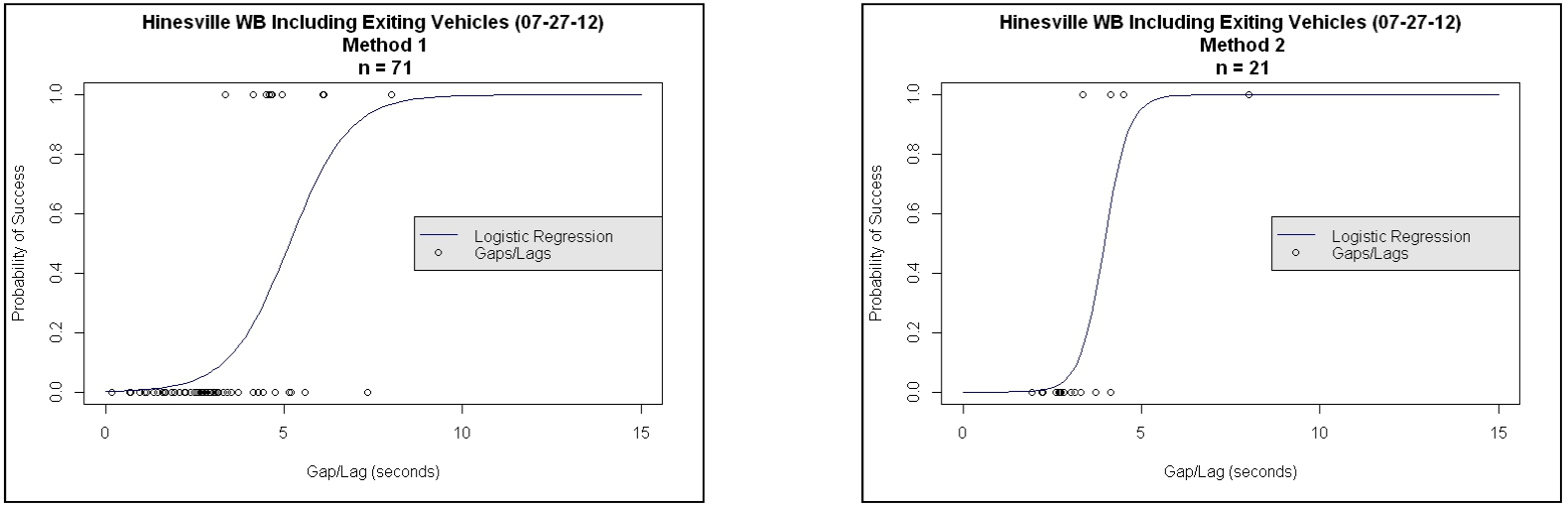
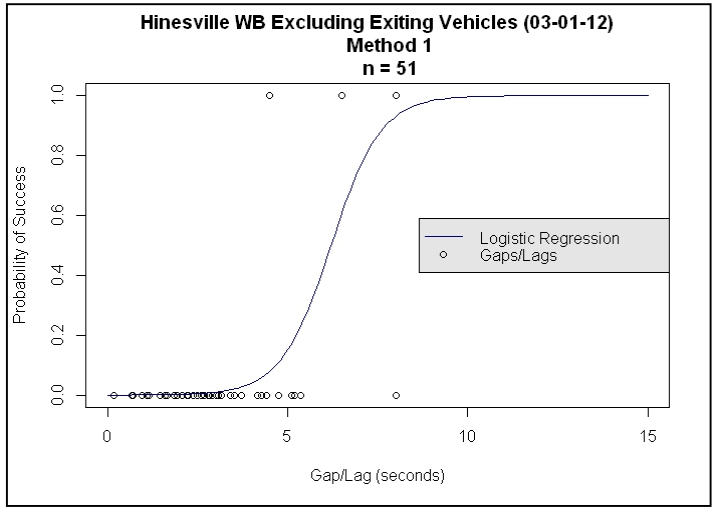


Figure 84. Critical headway including exiting vehicles for Hinesville westbound approach



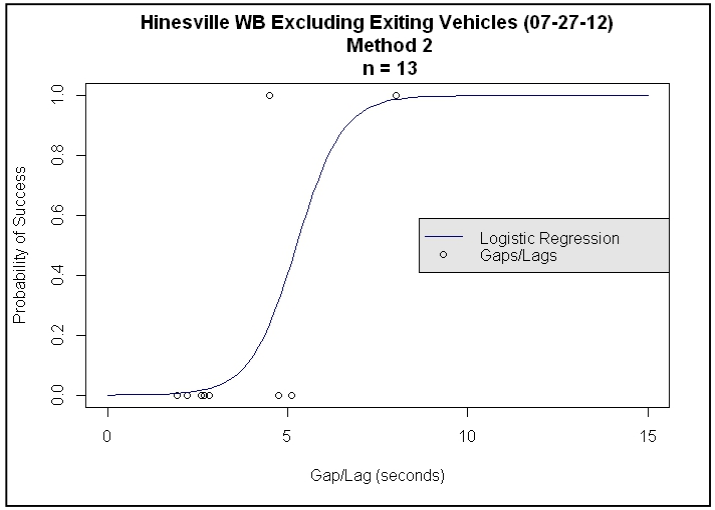


Figure 85. Critical headway excluding exiting vehicles for Hinesville westbound approach

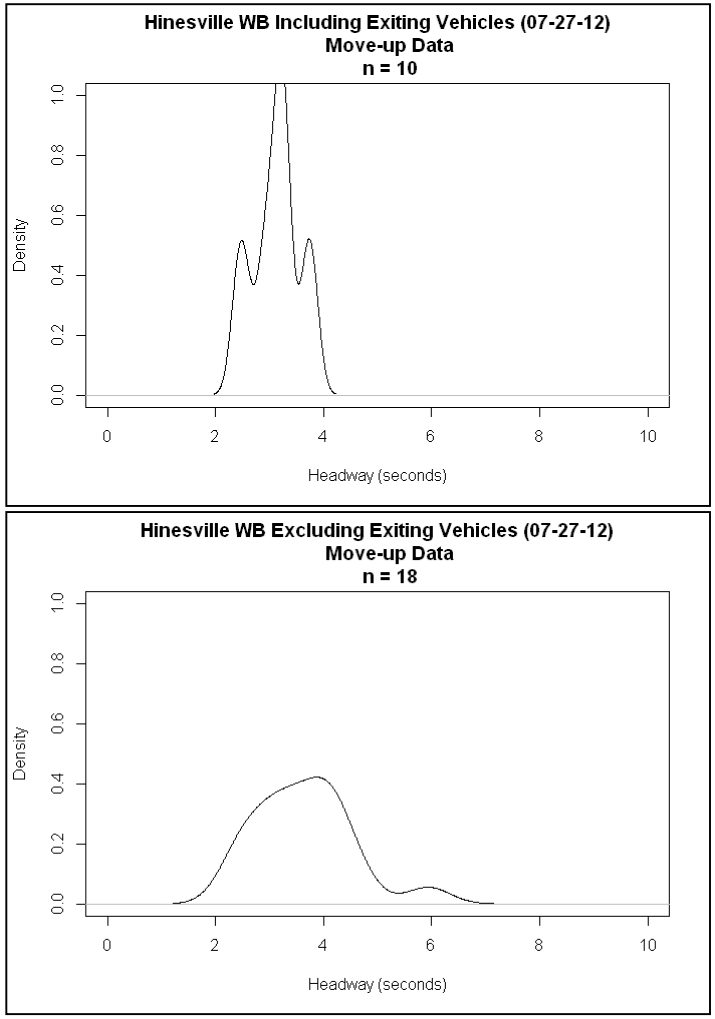


Figure 86. Follow-up headway for Hinesville westbound approach

Table 38. Data summary sheet for Hinesville southbound approach

Site	Hinesville		
ID	HIN01-SB		
Approach	Southbound		
Intersection	Memorial Dr./N. Main St.		
County	Liberty		
City	Hinesville		
GDOT District	5		
AADT	5090		
Date of data collection	Friday, July 27, 2012		
Time of data collection	3:38 PM – 5:59 PM		
Video duration	2:21:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	402	172	
Number of circulating vehicles	247	106	
Number of exiting vehicles	282	120	

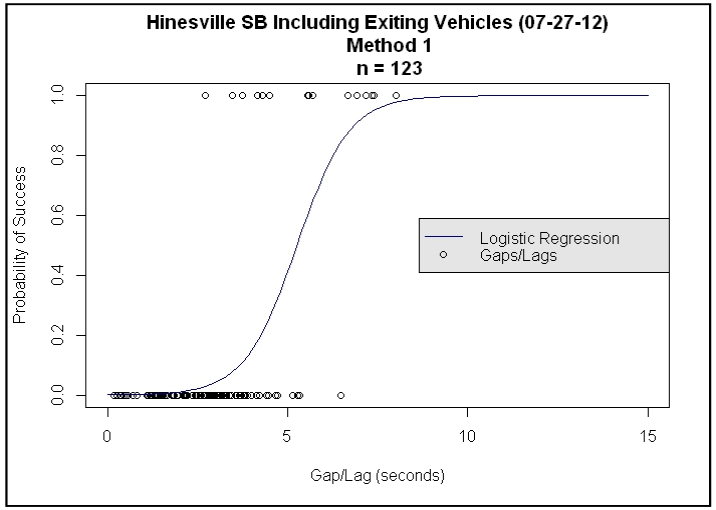
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	9.200 (6.4)	23	9.493 (7.7)	153	3.195 (1.0)	28	2.256 (1.2)	72
Excluding exiting vehicles	15.938 (16.0)	6	12.975 (9.6)	104	3.512 (1.0)	12	2.444 (1.9)	47

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.933 (0.6)	84
Excluding exiting vehicles	n/a (n/a)	0	4.0	3.317 (1.0)	120

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.258 (2.0)	123	5.528 (2.1)	14	n/a (n/a)	0
Excluding exiting vehicles	7.111 (2.1)	65	6.339 (1.2)	3	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



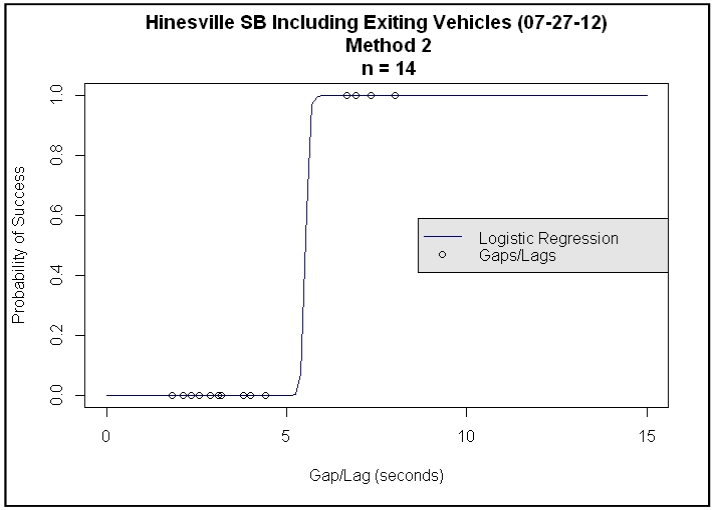
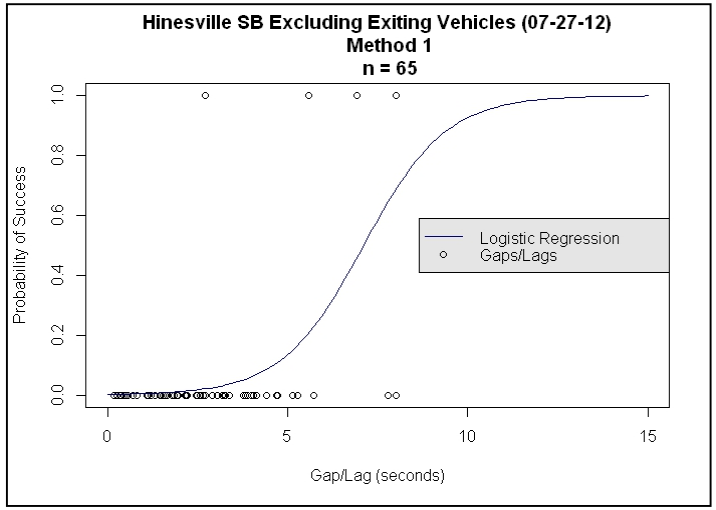


Figure 87. Critical headway including exiting vehicles for Hinesville southbound approach



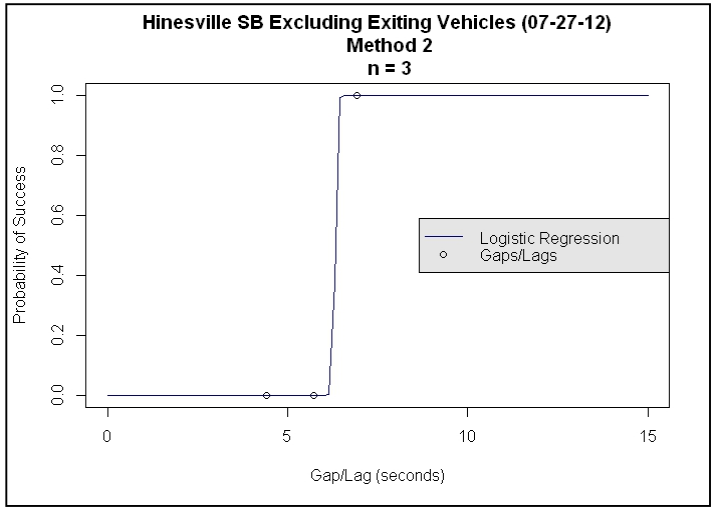


Figure 88. Critical headway excluding exiting vehicles for Hinesville southbound approach

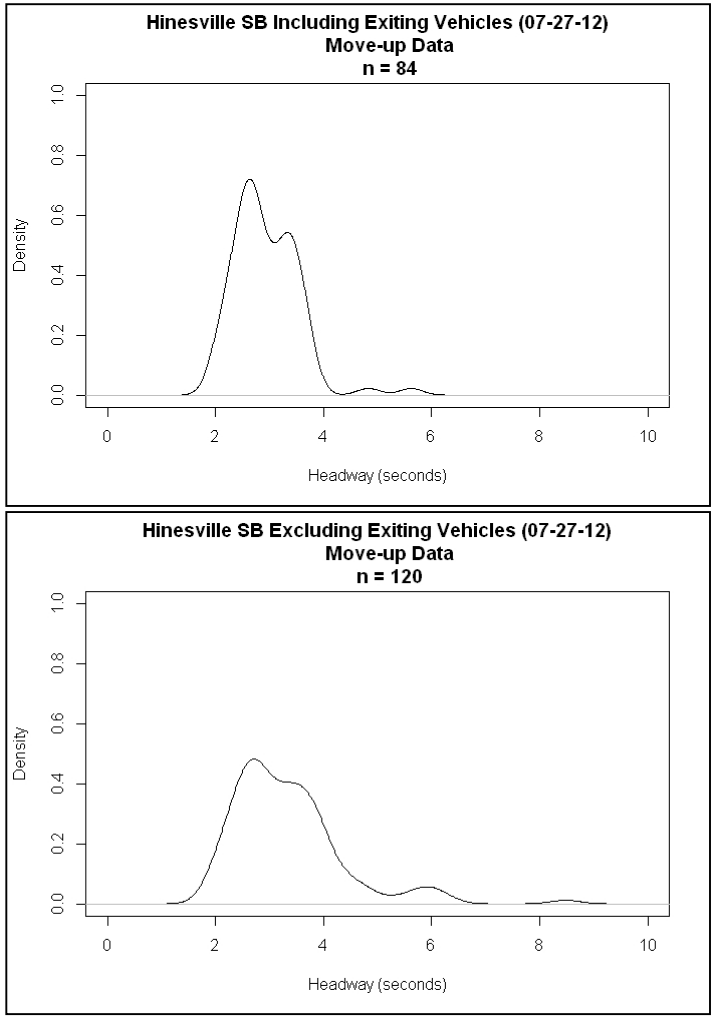


Figure 89. Follow-up headway for Hinesville southbound approach

Table 39. Data summary sheet for Holly Springs eastbound approach

Site	Holly Springs		
ID	HOL01-EB		
Approach	Eastbound		
Intersection	Holly Springs Rd./Davis Rd.		
County	Cobb		
City	Marietta		
GDOT District	7		
AADT	n/a		
Date of data collection	Tuesday, October 11, 2012		
Time of data collection	4:07 PM – 6:05 PM		
Video duration	1:58:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	243	124	
Number of circulating vehicles	759	386	
Number of exiting vehicles	185	95	

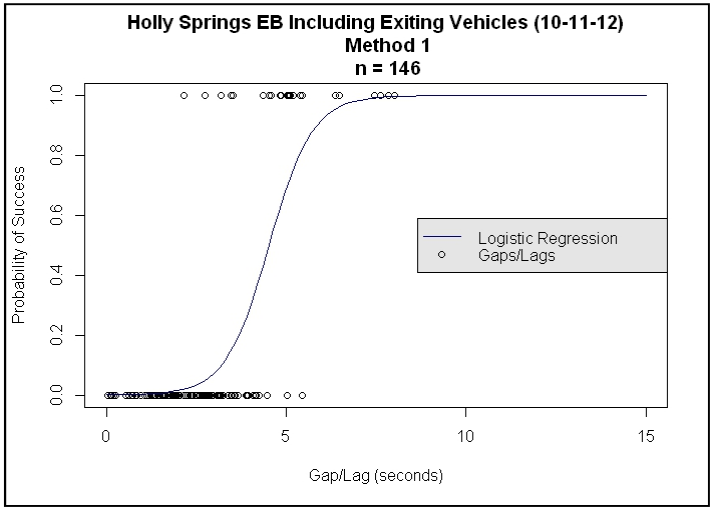
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	7.336 (4.0)	32	9.133 (8.0)	120	2.822 (0.8)	58	1.608 (1.1)	56
Excluding exiting vehicles	9.945 (5.9)	26	11.474 (10.6)	107	3.042 (1.2)	49	1.584 (1.1)	50

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.961 (0.5)	36
Excluding exiting vehicles	n/a (n/a)	0	4.0	3.107 (0.6)	51

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.522 (2.0)	146	4.434 (1.8)	56	n/a (n/a)	0
Excluding exiting vehicles	5.183 (2.2)	125	4.876 (2.0)	39	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



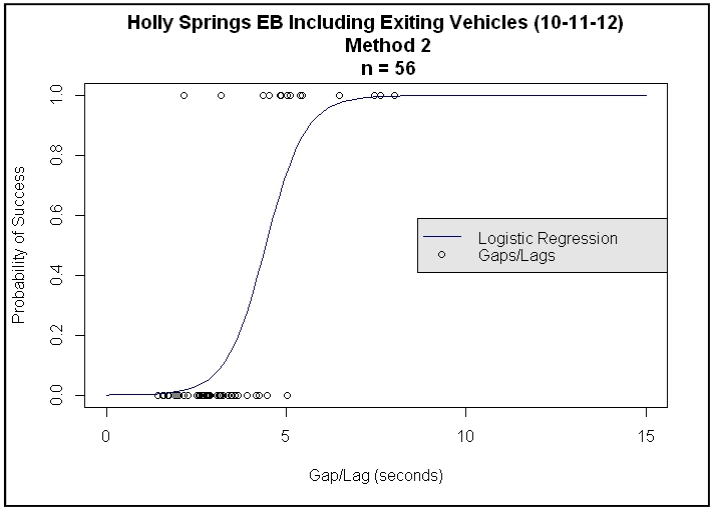
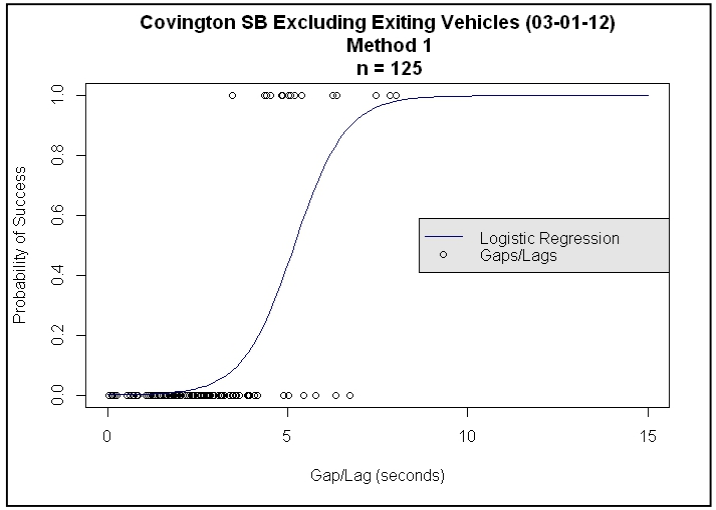


Figure 90. Critical headway including exiting vehicles for Holly Springs eastbound approach



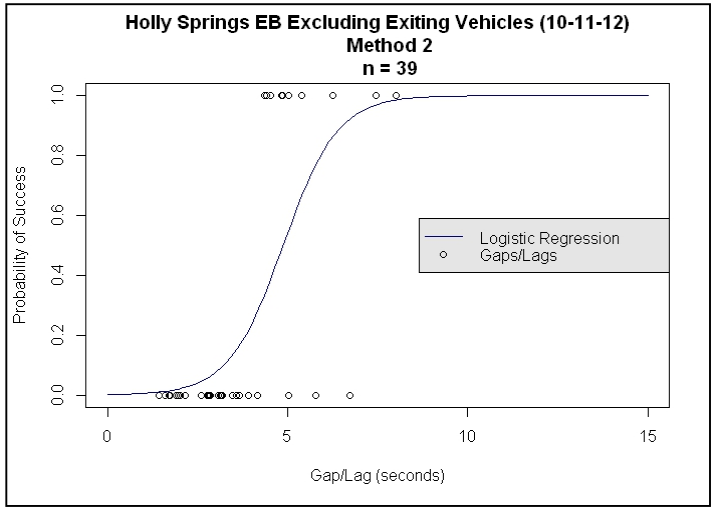


Figure 91. Critical headway excluding exiting vehicles for Holly Springs eastbound approach

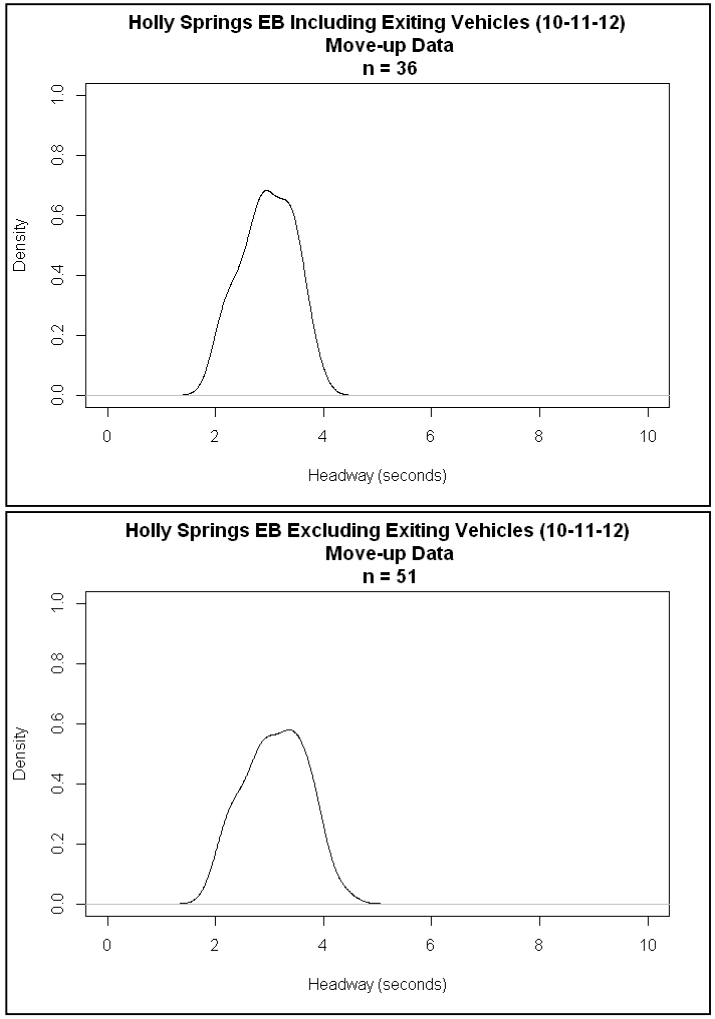


Figure 92. Follow-up headway for Holly Springs eastbound approach

Table 40. Data summary sheet for Holly Springs northbound approach

Site	Holly Springs		
ID	HOL01-NB		
Approach	Northbound		
Intersection	Holly Springs Rd./Davis Rd.		
County	Cobb		
City	Marietta		
GDOT District	7		
AADT	n/a		
Date of data collection	Tuesday, October 11, 2012		
Time of data collection	4:17 PM – 6:06 PM		
Video duration	1:49:00		
Queuing periods at least 1 minute long	1		
Total number of queued minutes	1		
	Total data	vph data	
Number of entering vehicles	275	152	
Number of circulating vehicles	1074	592	
Number of exiting vehicles	394	217	

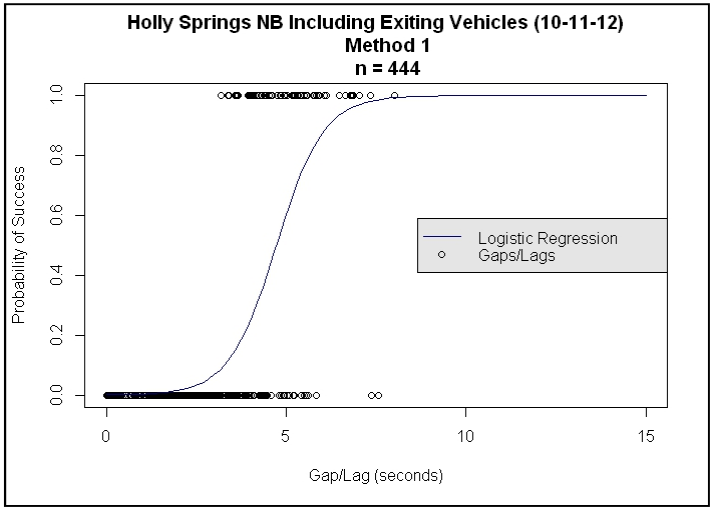
Source: Google Earth™, accessed 8/16/2013

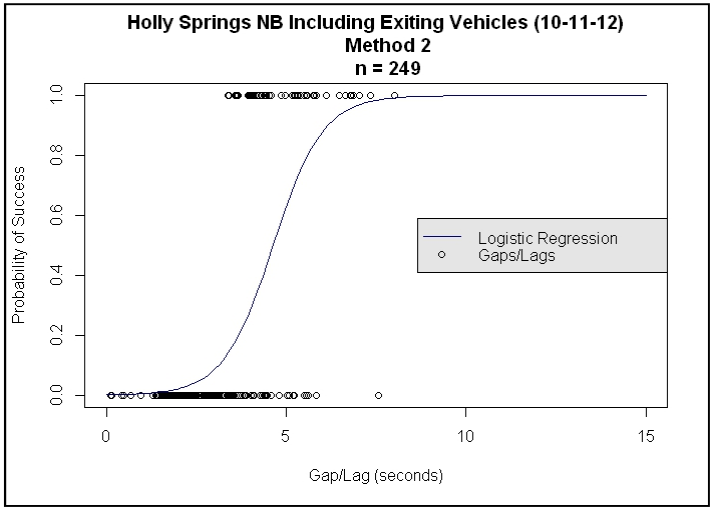
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.356 (3.2)	90	8.259 (6.7)	105	2.753 (1.1)	231	1.728 (1.2)	123
Excluding exiting vehicles	7.114 (4.4)	70	9.514 (8.6)	95	2.600 (0.9)	175	1.667 (1.2)	117

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	4.417 (n/a)	1	3.6	2.947 (0.7)	29
Excluding exiting vehicles	3.882 (0.7)	3	4.0	3.137 (0.7)	42

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.727 (1.8)	444	4.638 (1.7)	249	4.111 (1.0)	7
Excluding exiting vehicles	4.621 (1.9)	362	4.487 (1.8)	176	3.038 (1.4)	4

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





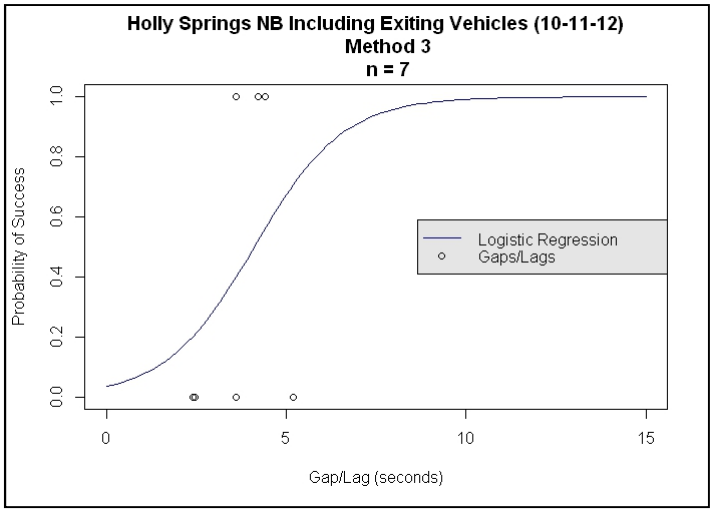
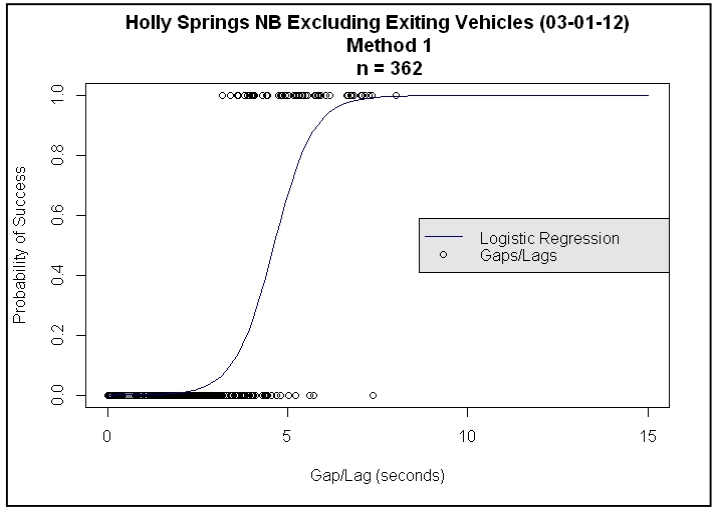
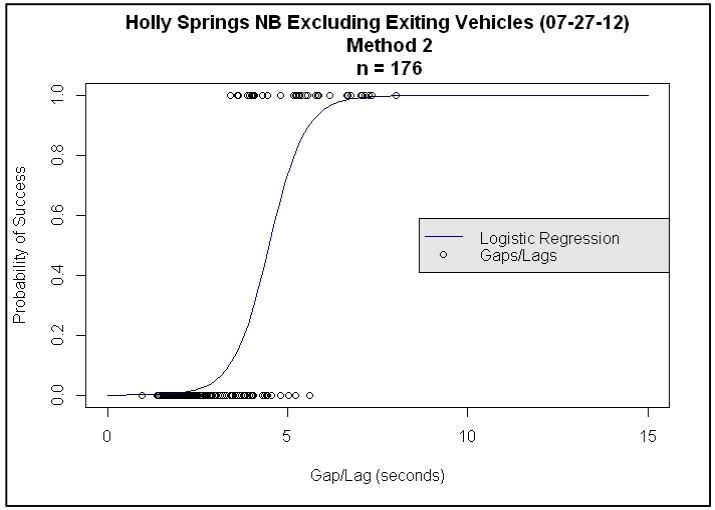


Figure 93. Critical headway including exiting vehicles for Holly Springs northbound approach





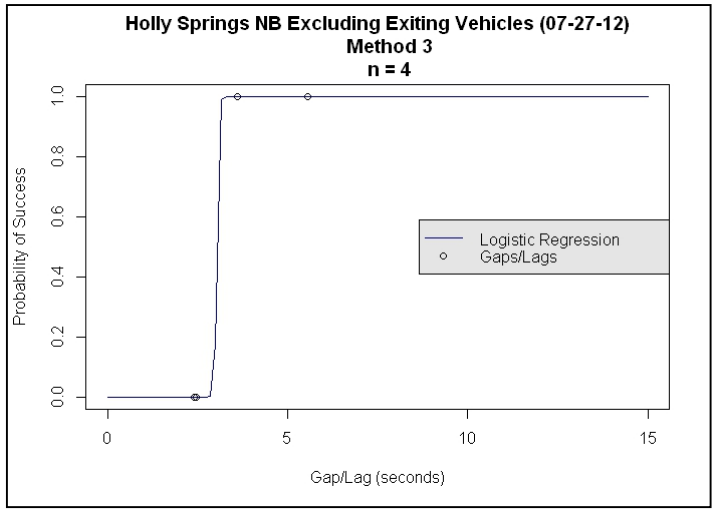
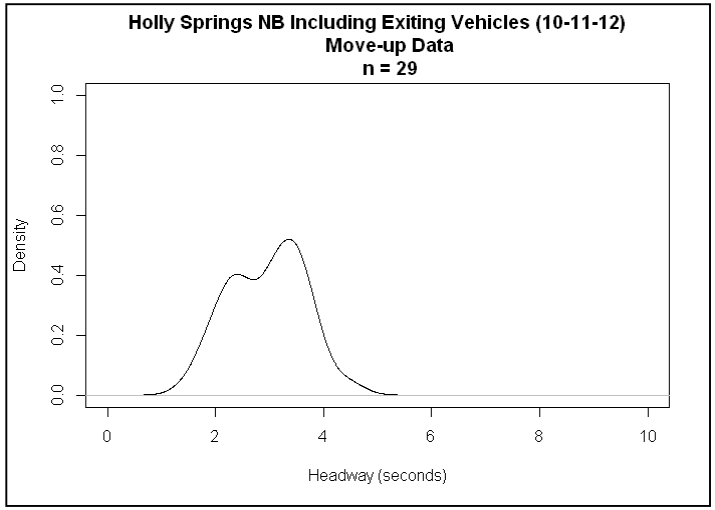
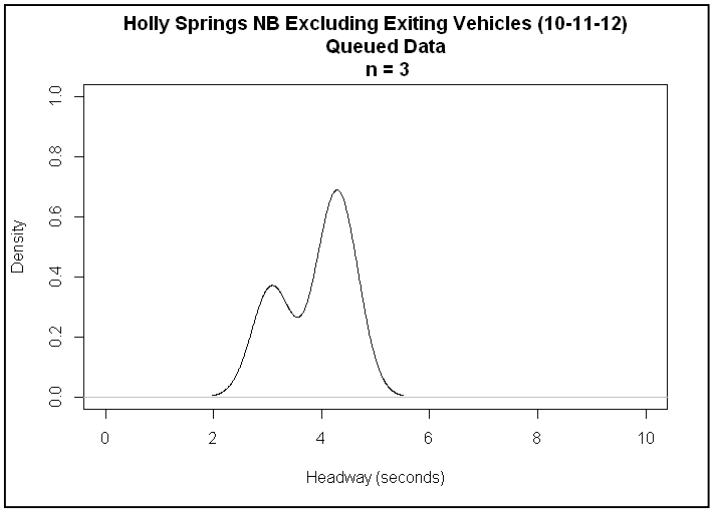


Figure 94. Critical headway excluding exiting vehicles for Holly Springs northbound approach





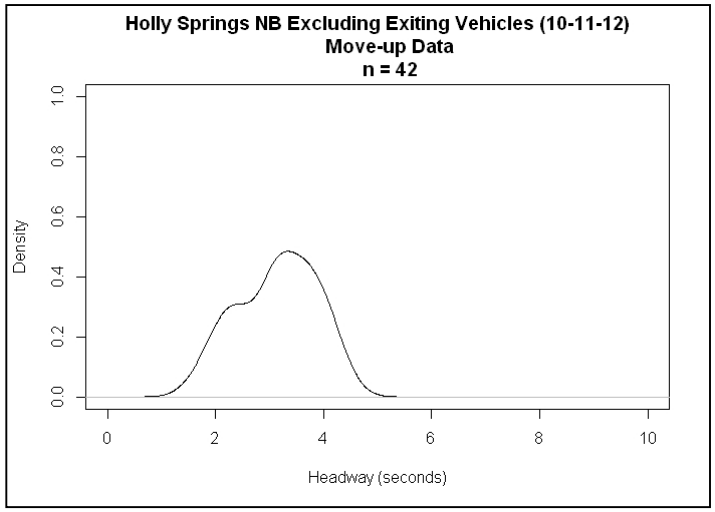


Figure 95. Follow-up headway for Holly Springs northbound approach

Table 41. Data summary sheet for Villa Rica southwestbound approach

Site	Villa Rica		
ID	VIL01-SWB		
Approach	Southwestbound		
Intersection	Villa Rica Rd. SW/W. Sandtown Rd. SW		
County	Cobb		
City	Marietta		
GDOT District	7		
AADT	n/a		
Date of data collection	Tuesday, March 27, 2012		
Time of data collection	4:22 PM – 6:46 PM		
Video duration	2:24:00		
Queuing periods at least 1 minute long	8		
Total number of queued minutes	8		
	Total data	vph data	
Number of entering vehicles	1271	530	
Number of circulating vehicles	333	139	
Number of exiting vehicles	676	282	

Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	4.435 (2.3)	73	3.551 (2.9)	345	2.769 (0.8)	90	1.738 (1.0)	267
Excluding exiting vehicles	9.903 (8.8)	12	5.666 (4.6)	116	3.088 (1.4)	39	1.718 (1.4)	133

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.535 (0.6)	81	3.6	2.593 (0.6)	571
Excluding exiting vehicles	2.812 (1.0)	133	4.0	2.878 (0.9)	825

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.038 (1.4)	430	3.384 (1.2)	50	4.001 (1.0)	7
Excluding exiting vehicles	6.667 (1.9)	184	4.521 (1.6)	6	5.333 (0.7)	2

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation

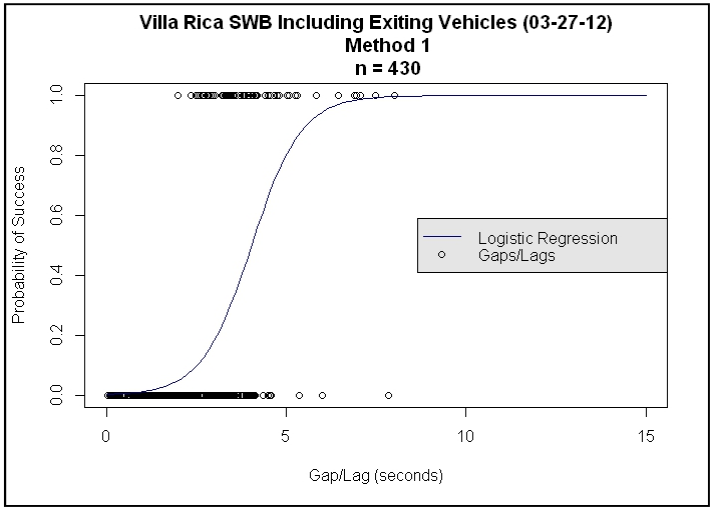
[1]Follow up headway observations during all user defined queuing periods > 1 minute

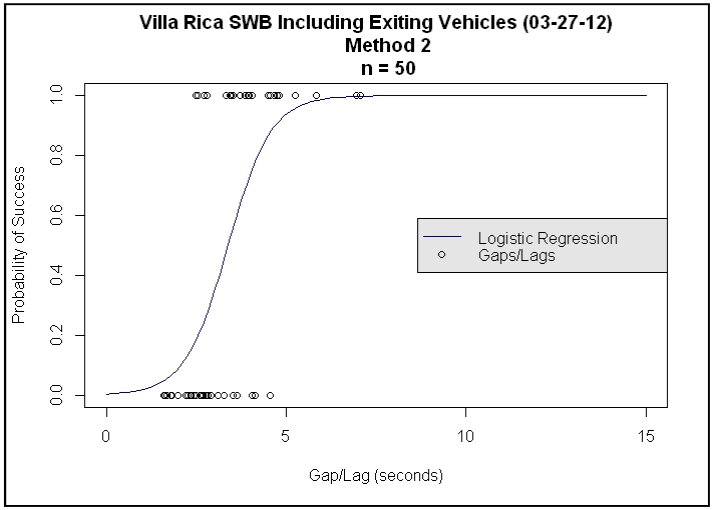
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts

[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)

[4]Observations that include a rejected gap

[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





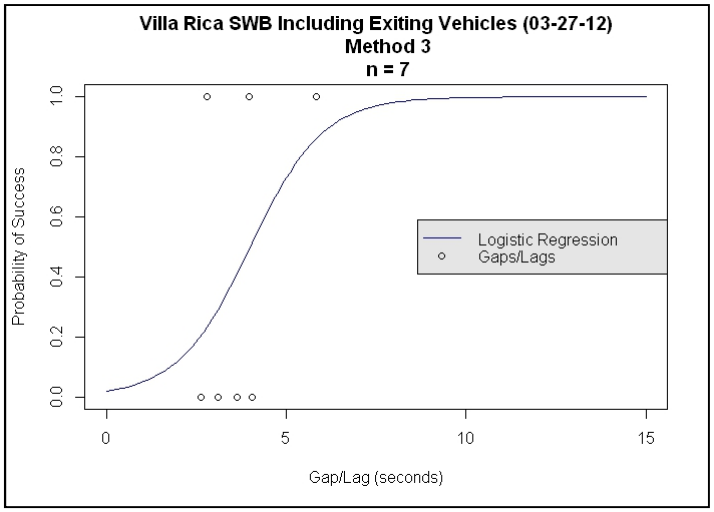
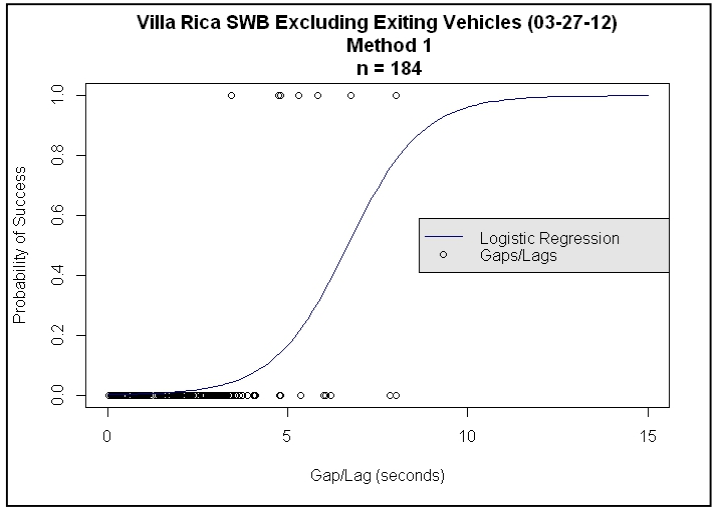
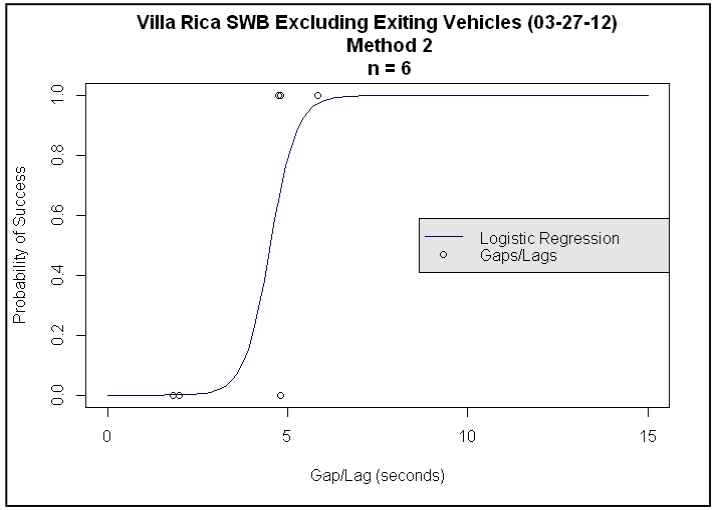


Figure 96. Critical headway including exiting vehicles Villa Rica southwestbound approach





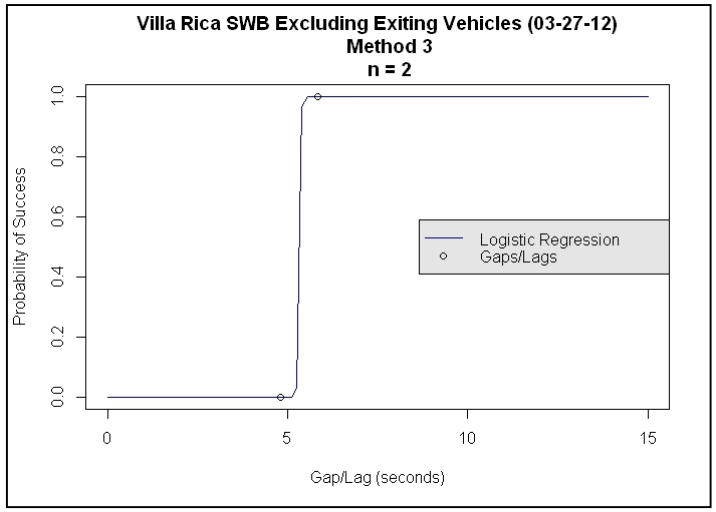


Figure 97. Critical headway excluding exiting vehicles for Villa Rica southwestbound approach

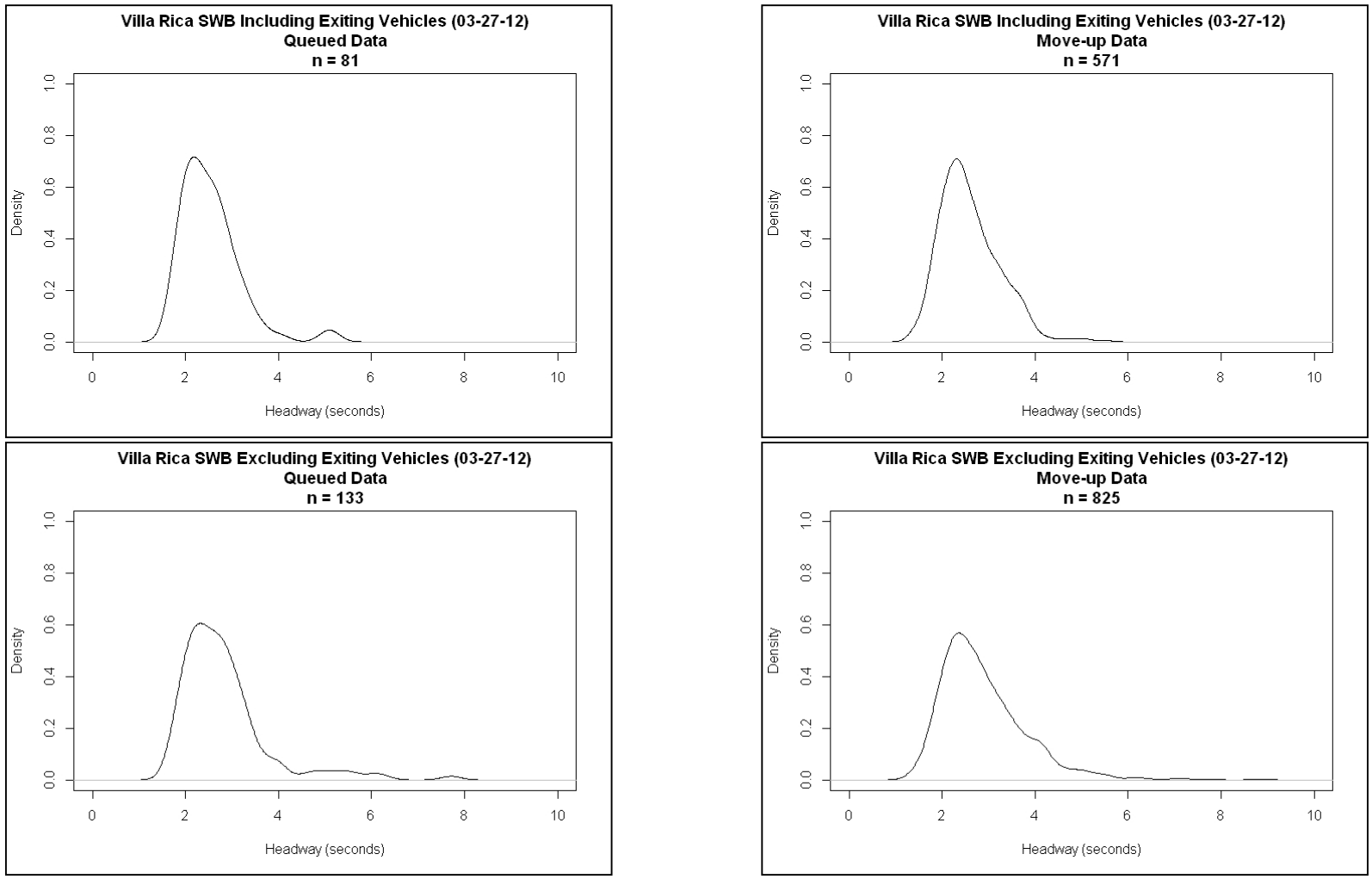


Figure 98. Follow-up headway for Villa Rica southwestbound approach

Table 42. Data summary sheet for Newnan eastbound approach

Site	Newnan		
ID	NEW01-EB		
Approach	Eastbound		
Intersection	E. Broad St./E. Newnan Rd.		
County	Coweta		
City	Newnan		
GDOT District	3		
AADT	9790		
Date of data collection	Thursday, October 25, 2012		
Time of data collection	7:33 AM – 9:28 AM		
Video duration	1:55:00		
Queuing periods at least 1 minute long	1		
Total number of queued minutes	1		
	Total data	vph data	
Number of entering vehicles	536	280	
Number of circulating vehicles	388	203	
Number of exiting vehicles	665	347	

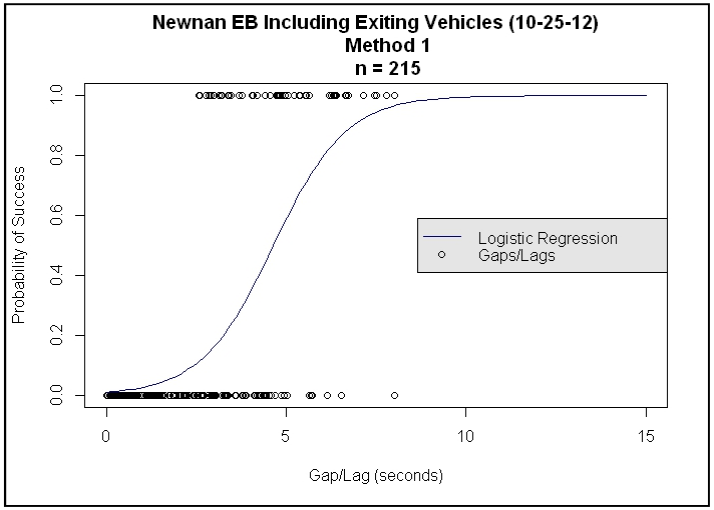
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.464 (6.4)	58	4.282 (3.8)	252	2.837 (1.5)	68	1.676 (1.4)	89
Excluding exiting vehicles	7.162 (2.8)	22	7.720 (7.8)	146	3.247 (2.3)	37	1.609 (1.8)	58

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	4.077 (2.6)	9	3.6	3.037 (0.8)	120
Excluding exiting vehicles	3.892 (2.5)	10	4.0	3.167 (0.9)	172

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.647 (2.1)	215	5.045 (2.1)	64	n/a (n/a)	0
Excluding exiting vehicles	5.974 (2.5)	117	4.883 (2.6)	9	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



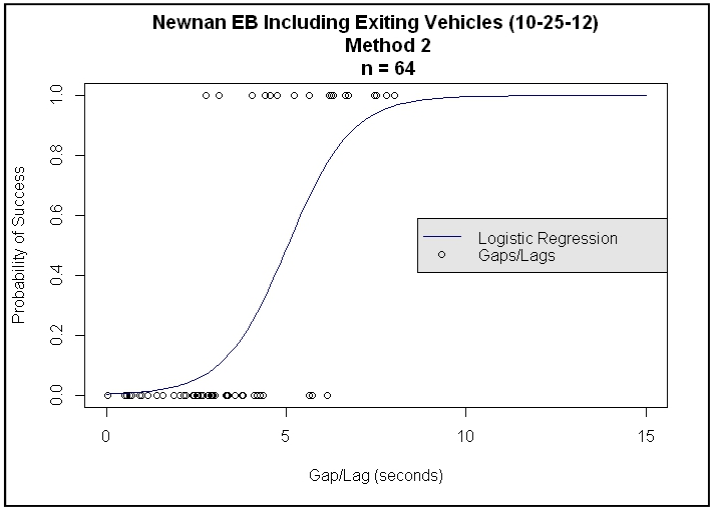
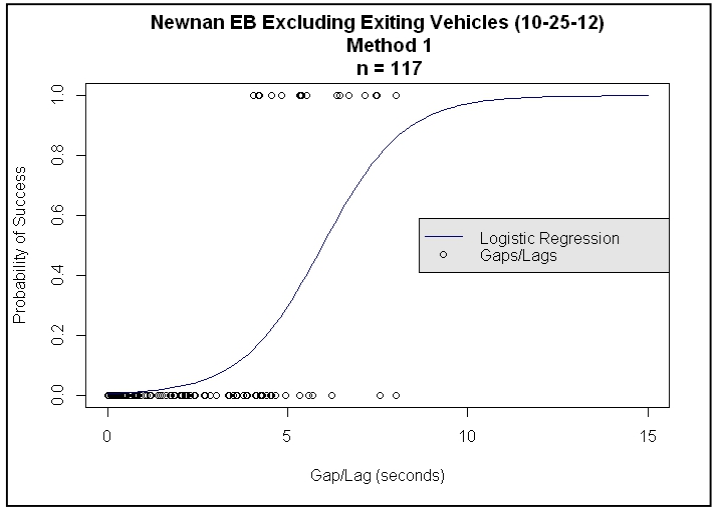


Figure 99. Critical headway including exiting vehicles for Newnan eastbound approach



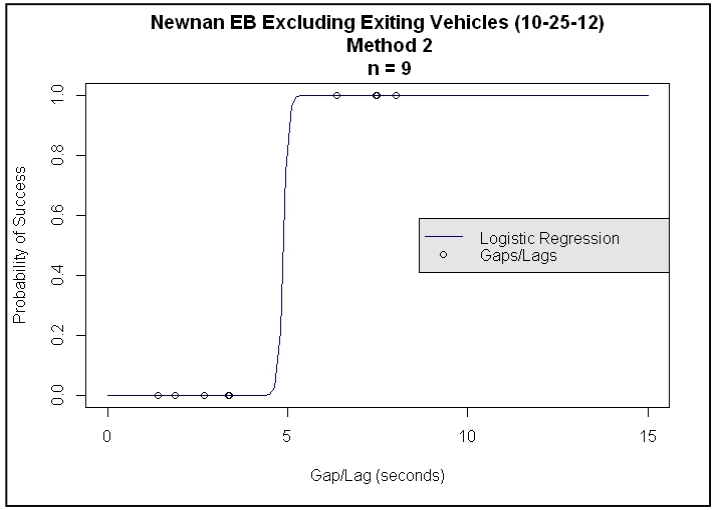


Figure 100. Critical headway excluding exiting vehicles for Newnan eastbound approach

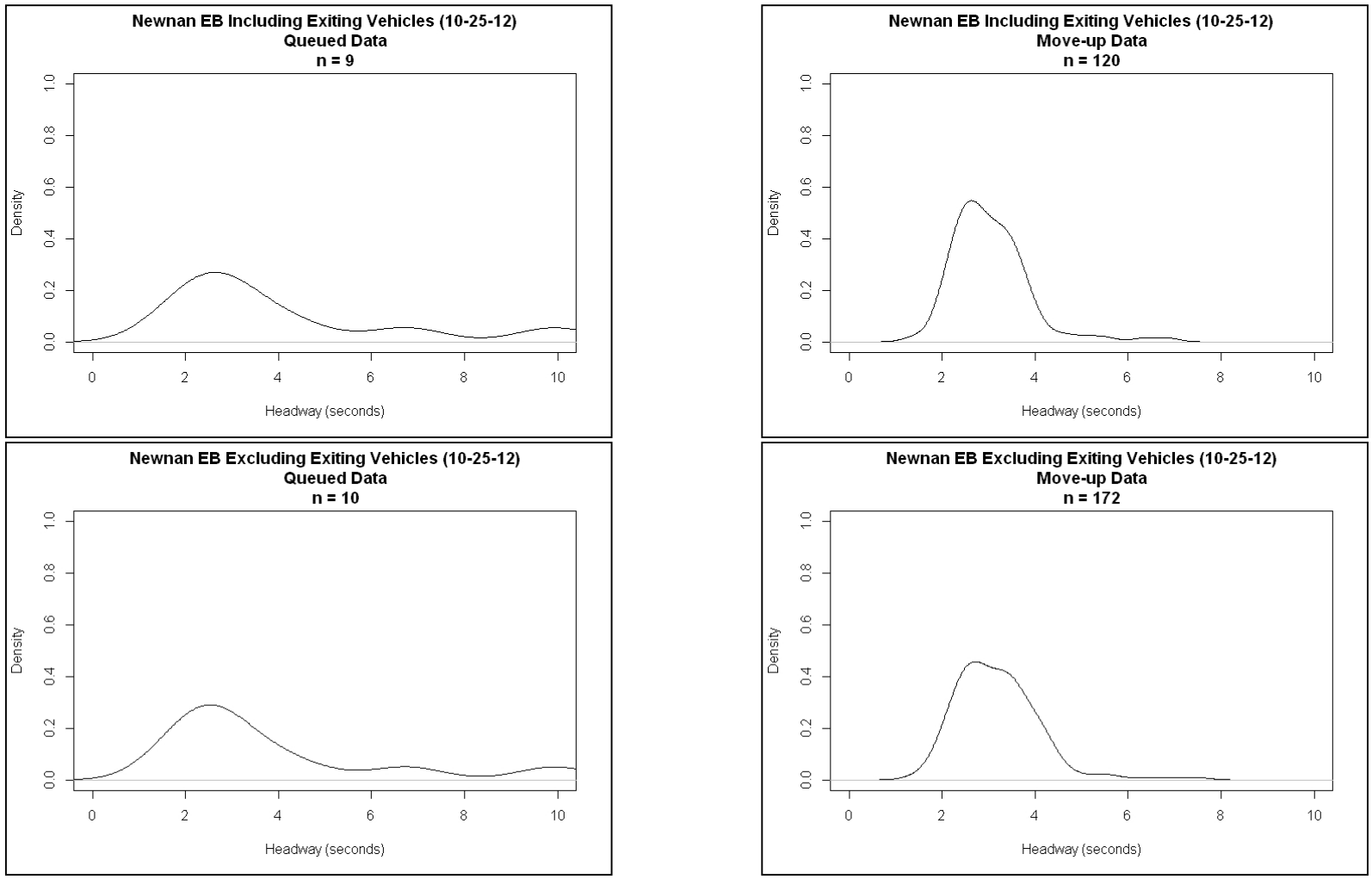


Figure 101. Follow-up headway for Newnan eastbound approach

Table 43. Data summary sheet for Newnan westbound approach

Site	Newnan		
ID	NEW01-WB		
Approach	Westbound		
Intersection	E. Broad St./E. Newnan Rd.		
County	Coweta		
City	Newnan		
GDOT District	3		
AADT	9790		
Date of data collection	Thursday, October 25, 2012		
Time of data collection	7:35 AM – 9:27 AM		
Video duration	1:52:00		
Queuing periods at least 1 minute long	6		
Total number of queued minutes	6		
	Total data	vph data	
Number of entering vehicles	690	370	
Number of circulating vehicles	461	247	
Number of exiting vehicles	547	294	

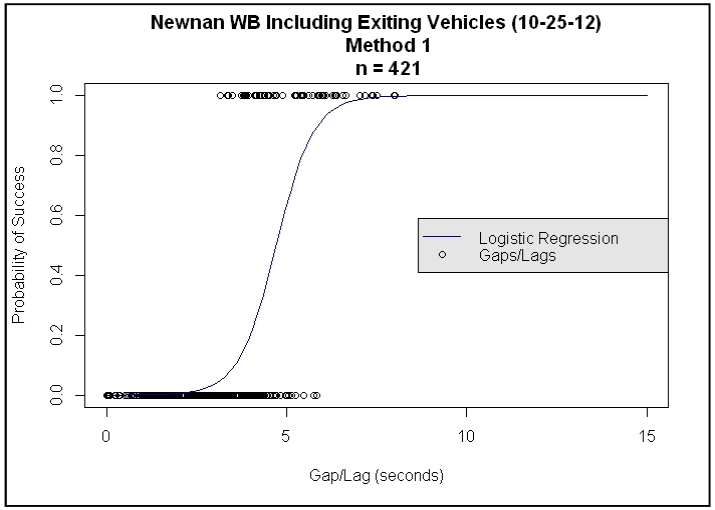
Source: Google Earth™, accessed 8/16/2013

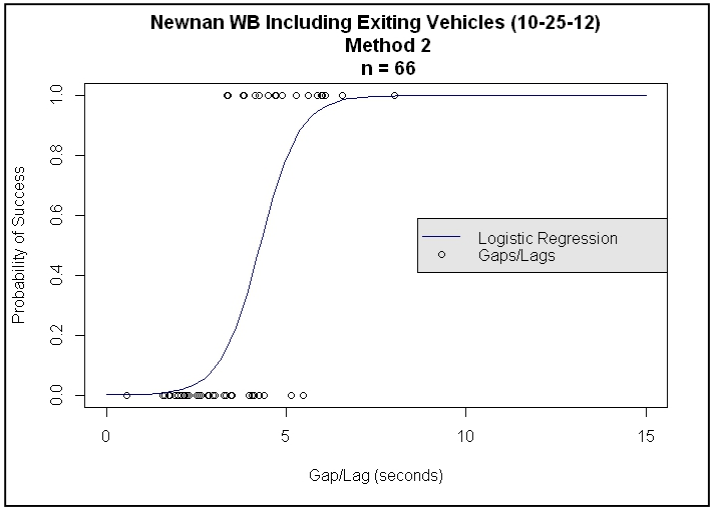
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	6.572 (3.8)	86	4.855 (4.4)	181	3.080 (1.0)	111	2.436 (1.2)	224
Excluding exiting vehicles	10.742 (9.2)	25	7.752 (8.0)	116	2.774 (0.9)	60	2.128 (9.2)	139

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.927 (0.8)	32	3.6	3.113 (0.9)	252
Excluding exiting vehicles	3.242 (0.9)	52	4.0	3.409 (1.2)	368

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	4.711 (1.7)	421	4.276 (1.8)	66	4.138 (1.3)	12
Excluding exiting vehicles	5.587 (1.8)	221	4.538 (2.2)	16	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





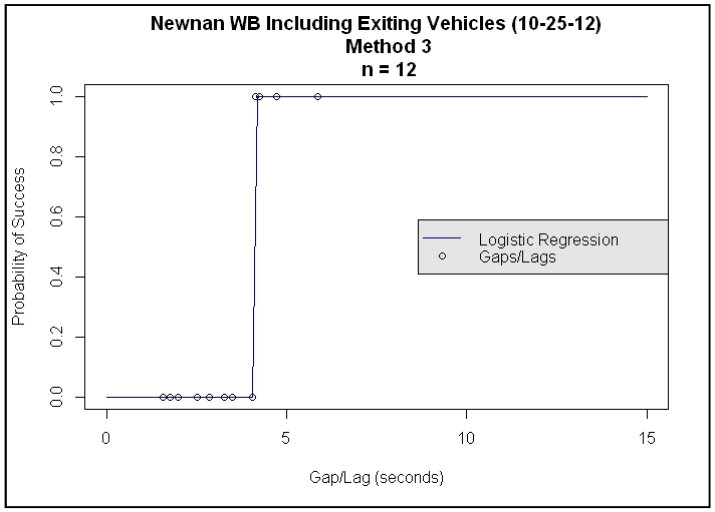
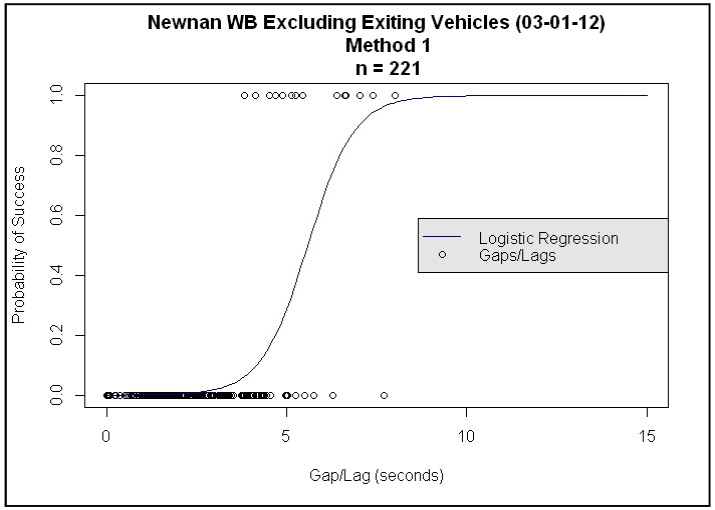


Figure 102. Critical headway including exiting vehicles for Newnan westbound approach



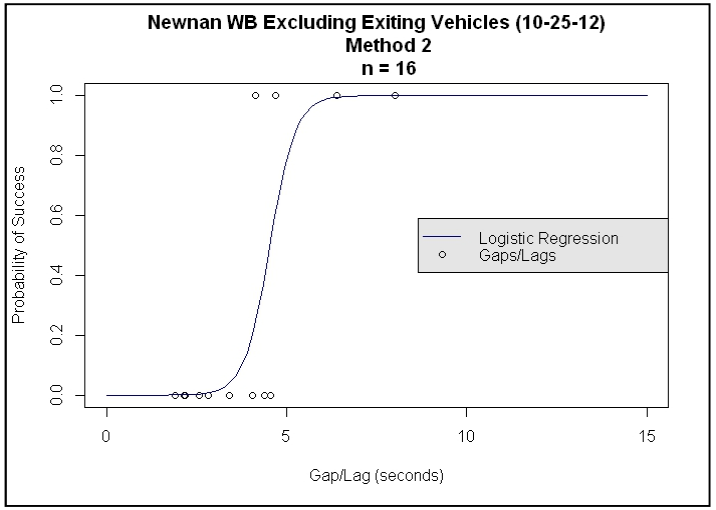


Figure 103. Critical headway excluding exiting vehicles for Newnan westbound approach

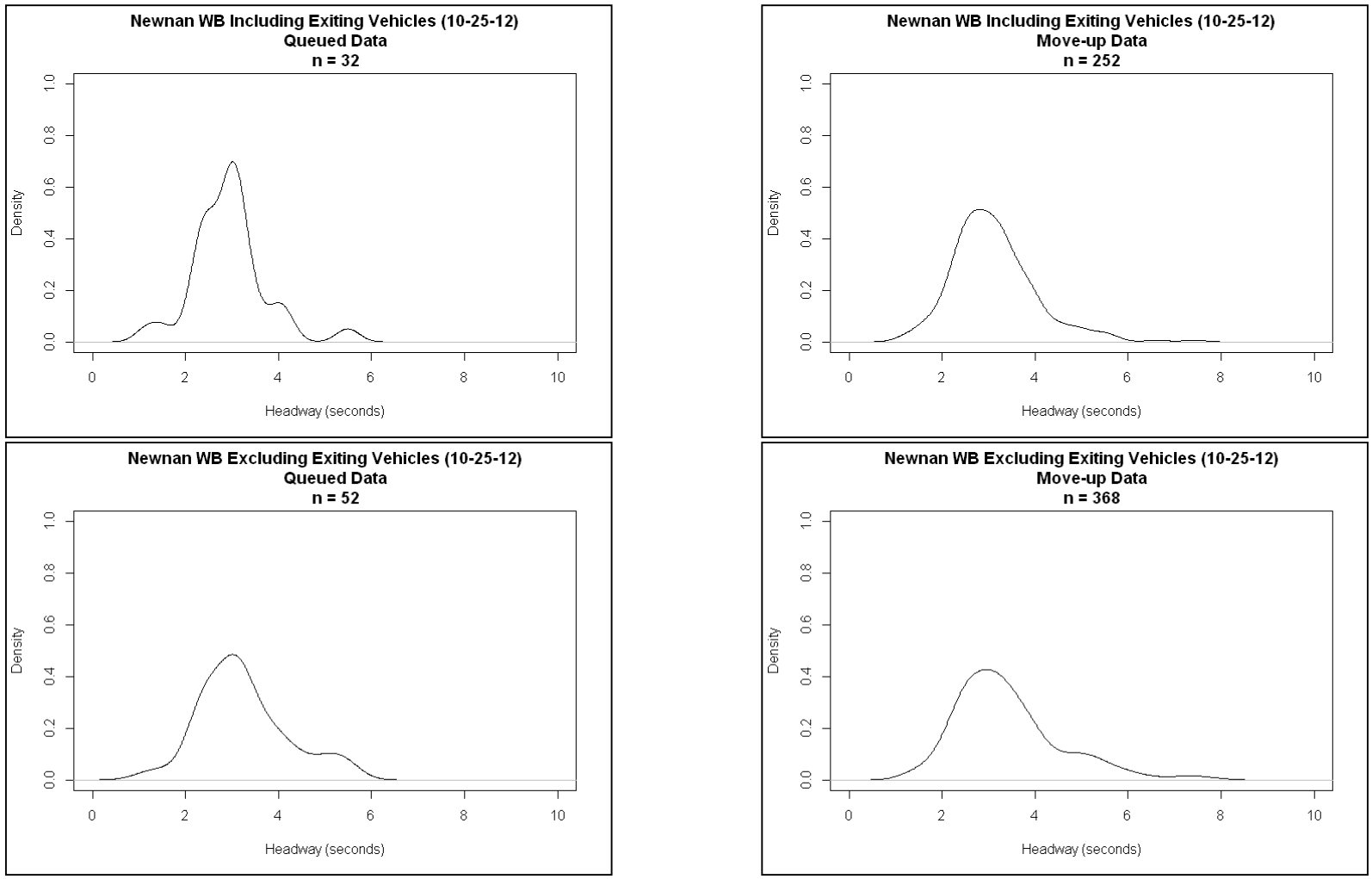


Figure 104. Follow-up headway for Newnan westbound approach

Table 44. Data summary sheet for Roswell eastbound approach (05/15/12)

Site	Roswell		
ID	ROS01-EB		
Approach	Eastbound		
Intersection	Grimes Bridge Rd./Norcross St./Warsaw Rd./Medlody Ln.		
County	Fulton		
City	Roswell		
GDOT District	7		
AADT	12440		
Date of data collection	Tuesday, May 15, 2012		
Time of data collection	4:27 PM – 6:33 PM		
Video duration	2:06:00		
Queuing periods at least 1 minute long	7		
Total number of queued minutes	8		
	Total data	vph data	
Number of entering vehicles	933	445	
Number of circulating vehicles	373	178	
Number of exiting vehicles	1732	825	

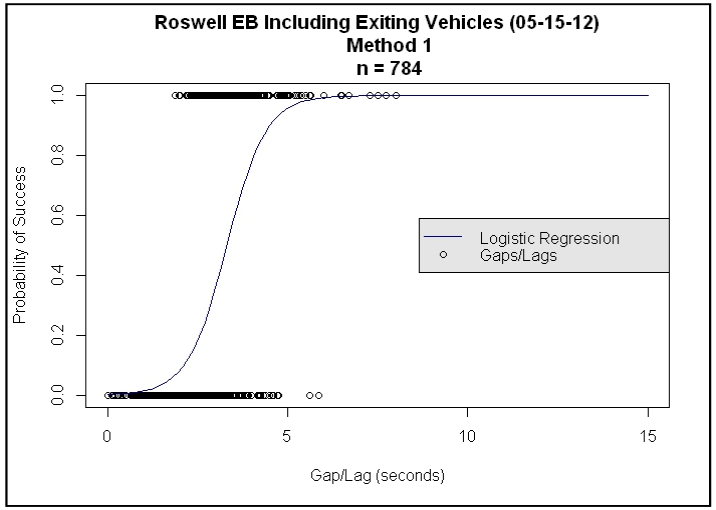
Source: Google Earth™, accessed 8/16/2013

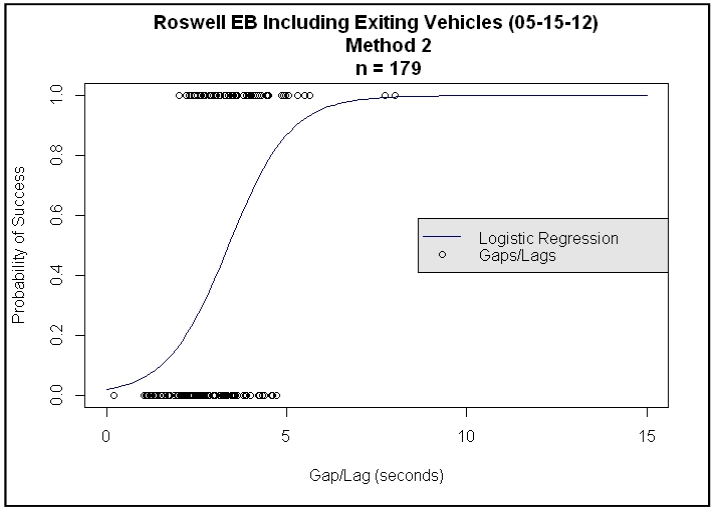
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	3.734 (1.4)	208	3.155 (2.4)	358	2.413 (0.9)	200	1.784 (0.7)	376
Excluding exiting vehicles	6.503 (3.1)	10	9.876 (8.3)	132	2.918 (1.2)	27	2.063 (1.5)	130

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.956 (0.8)	35	3.6	2.696 (0.7)	191
Excluding exiting vehicles	3.624 (1.5)	102	4.0	3.327 (1.1)	505

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	3.313 (1.2)	784	3.389 (1.2)	179	3.655 (0.9)	35
Excluding exiting vehicles	6.417 (1.6)	167	3.736 (1.3)	4	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





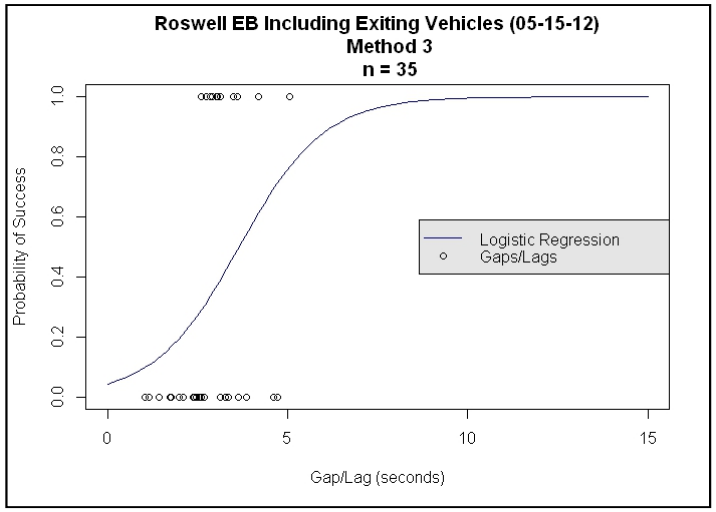
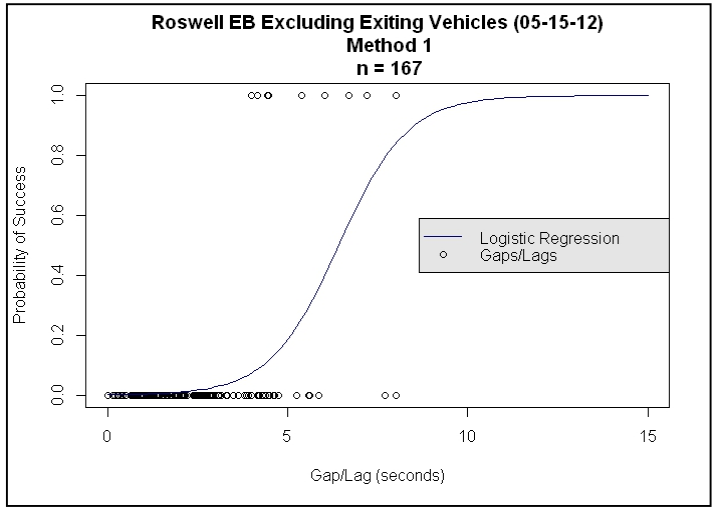


Figure 105. Critical headway including exiting vehicles for Roswell eastbound approach (05/15/12)



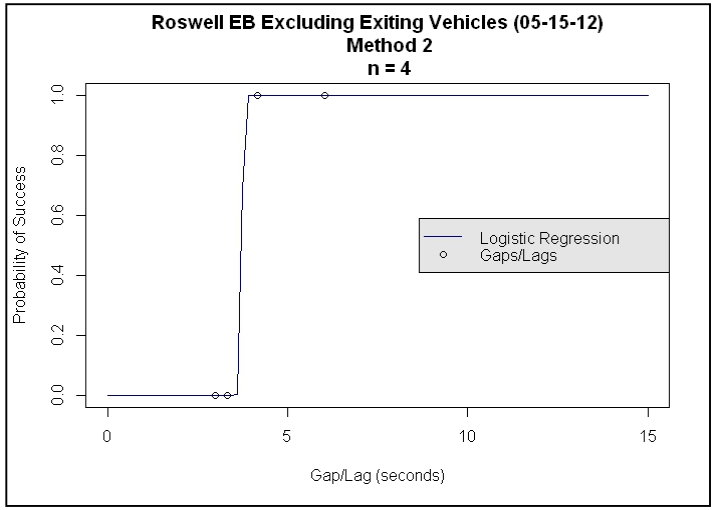


Figure 106. Critical headway excluding exiting vehicles for Roswell eastbound approach (05/15/12)

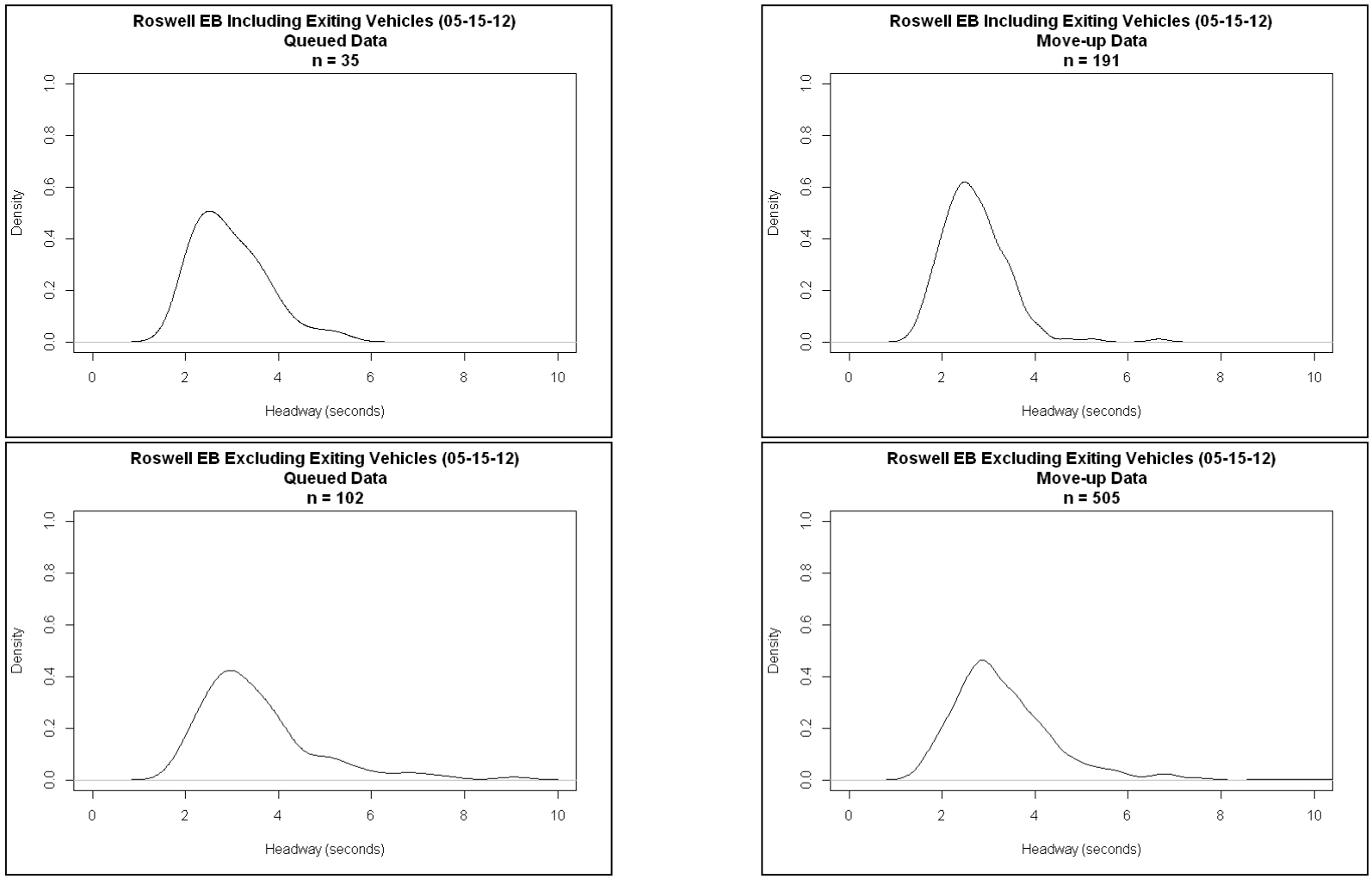


Figure 107. Follow-up headway for Roswell eastbound approach (05/15/12)

Table 45. Data summary sheet for Roswell southwestbound approach (5/15/12)

Site	Roswell		
ID	ROS01-SWB		
Approach	Southwestbound		
Intersection	Grimes Bridge Rd./Norcross St./Warsaw Rd./Medlody Ln.		
County	Fulton		
City	Roswell		
GDOT District	7		
AADT	n/a		
Date of data collection	Tuesday, May 15, 2012		
Time of data collection	4:17 PM – 6:24 PM		
Video duration	2:07:00		
Queuing periods at least 1 minute long		15	
Total number of queued minutes		17	
		Total data	vph data
Number of entering vehicles		987	467
Number of circulating vehicles		1118	529
Number of exiting vehicles		417	198

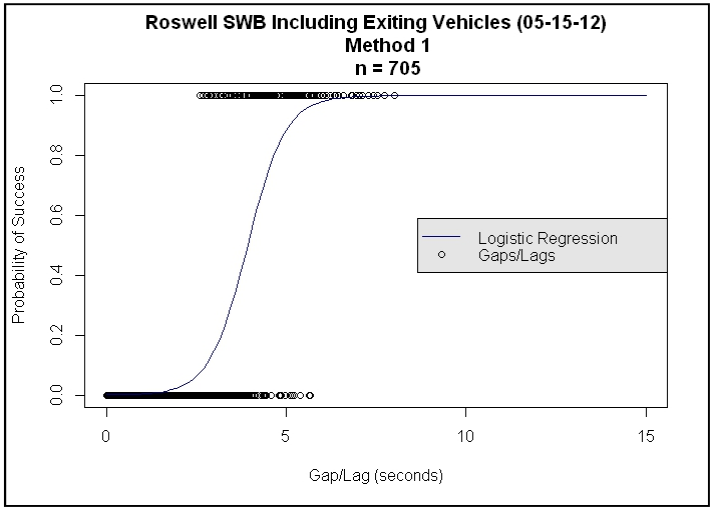
Source: Google Earth™, accessed 8/16/2013

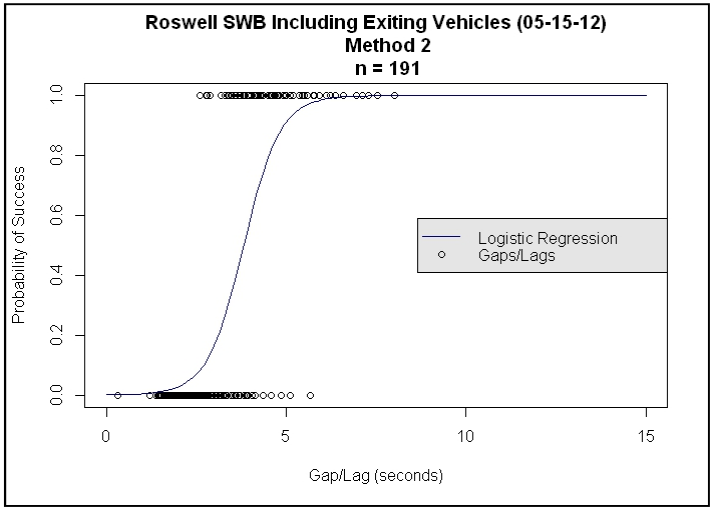
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	5.120 (2.2)	179	3.394 (3.1)	250	2.696 (0.9)	202	1.715 (1.0)	324
Excluding exiting vehicles	6.243 (4.3)	123	4.103 (4.7)	184	2.632 (0.9)	139	1.641 (1.1)	274

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.725 (0.7)	94	3.6	2.630 (0.7)	378
Excluding exiting vehicles	3.190 (1.5)	132	4.0	2.913 (1.0)	474

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	3.926 (1.6)	705	3.817 (1.5)	191	3.906 (1.3)	78
Excluding exiting vehicles	4.138 (1.8)	538	4.230 (1.7)	104	4.530 (1.6)	38

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





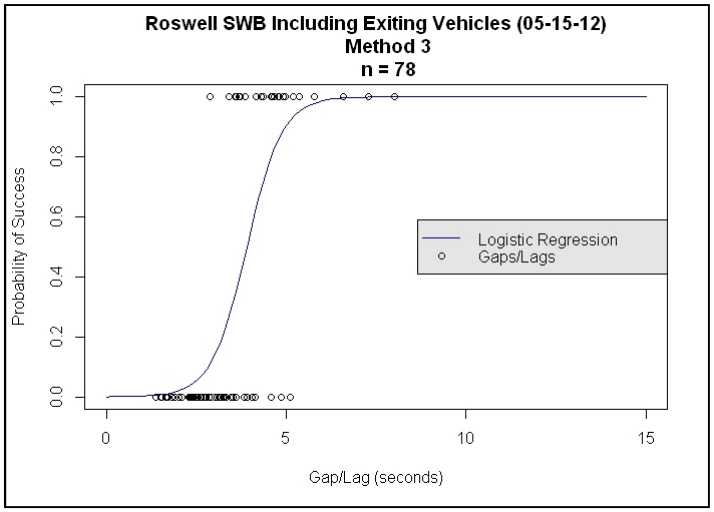
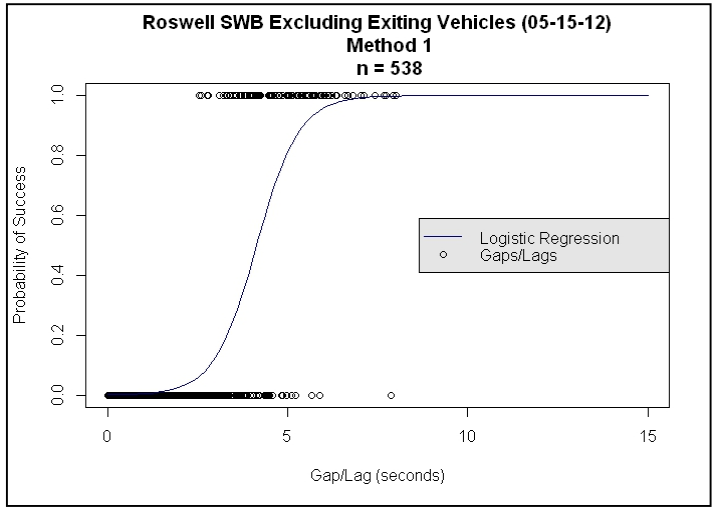
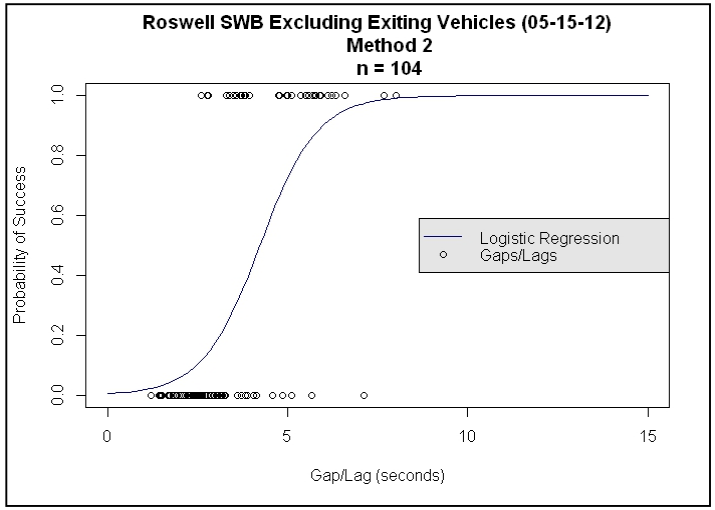


Figure 108. Critical headway including exiting vehicles for Roswell southwestbound approach (5/15/12)





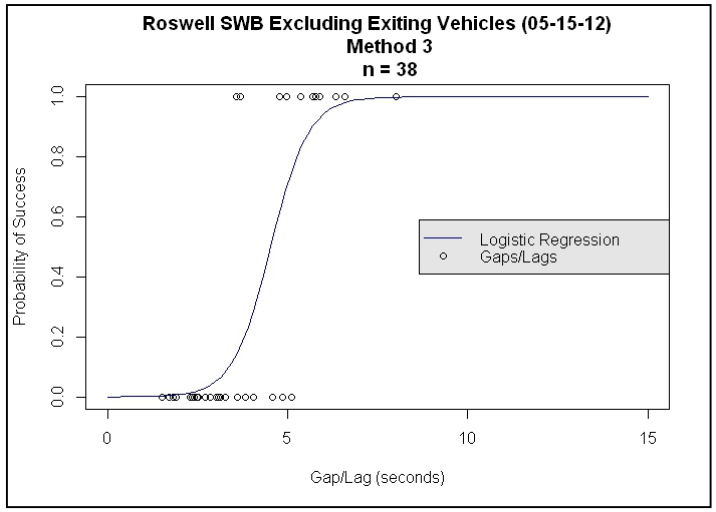


Figure 109. Critical headway excluding exiting vehicles for Roswell southwestbound approach (5/15/12)

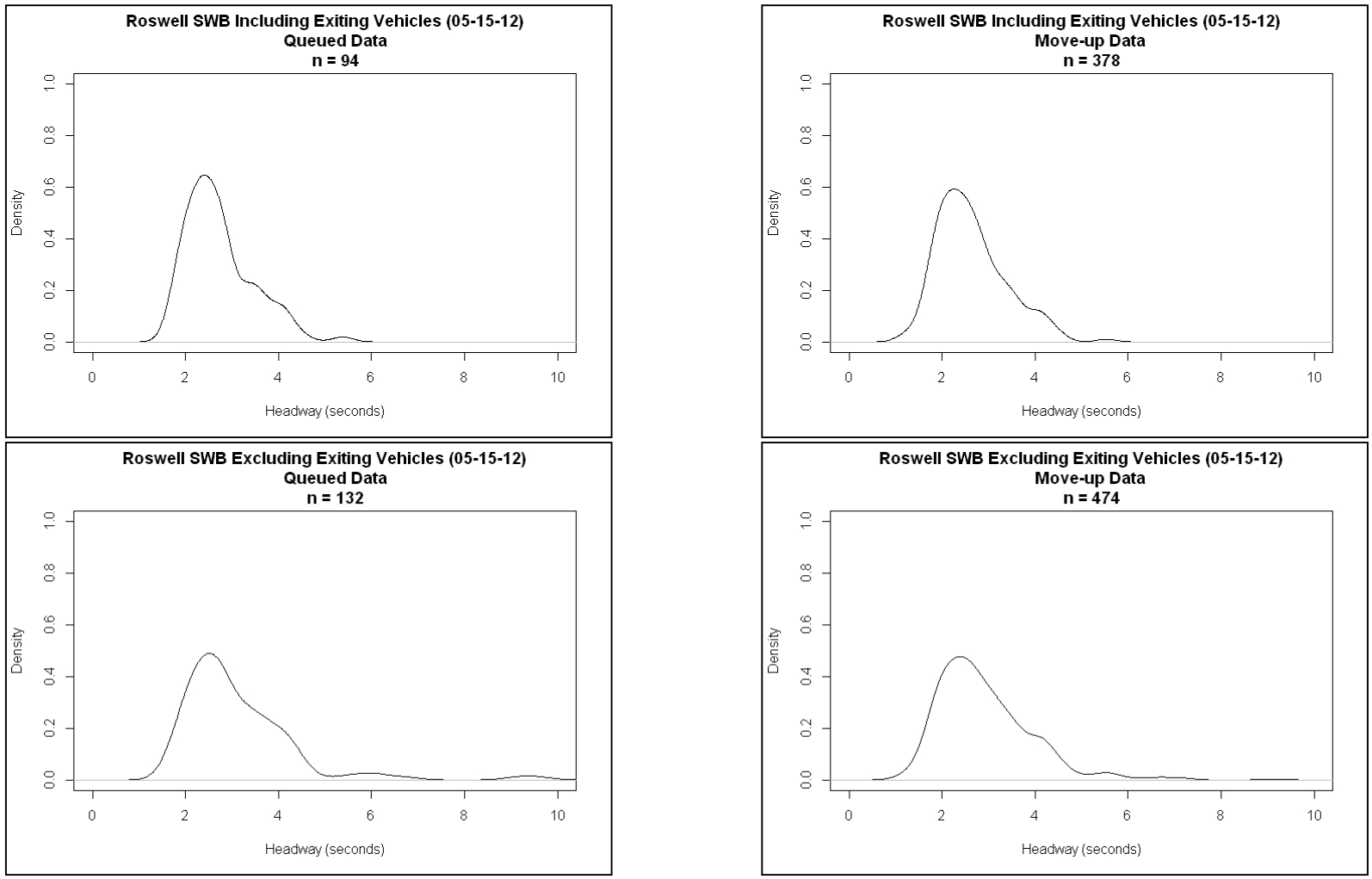


Figure 110. Follow-up headway for Roswell southwestbound approach (5/15/12)

Table 46. Data summary sheet for Roswell eastbound approach (10/23/12)

Site	Roswell		
ID	ROS02-EB		
Approach	Southwestbound		
Intersection	Grimes Bridge Rd./Norcross St./Warsaw Rd./Medlody Ln.		
County	Fulton		
City	Roswell		
GDOT District	7		
AADT	12440		
Date of data collection	Tuesday, October 23, 2012		
Time of data collection	3:45 PM – 5:13 PM		
Video duration	1:28:00		
Queuing periods at least 1 minute long	6		
Total number of queued minutes	7		
	Total data	vph data	
Number of entering vehicles	710	485	
Number of circulating vehicles	276	189	
Number of exiting vehicles	1273	868	

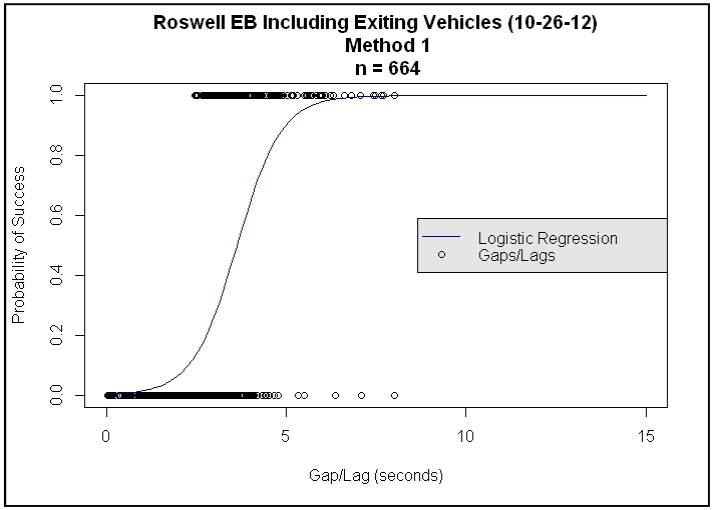
Source: Google Earth™, accessed 8/16/2013

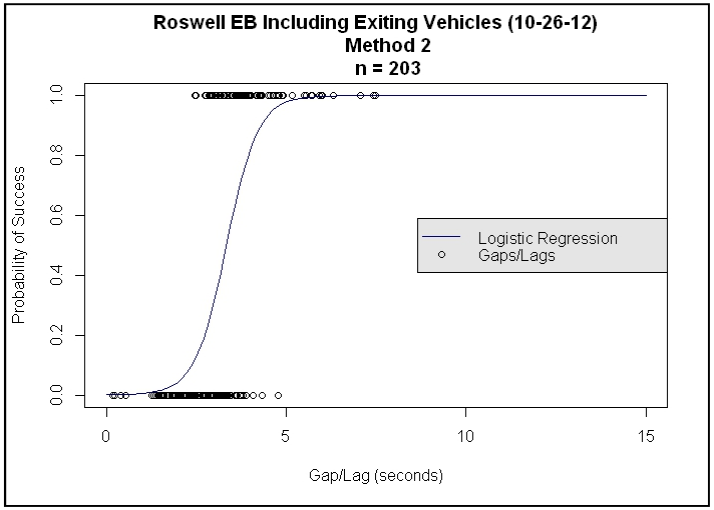
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	4.094 (1.2)	193	2.968 (1.5)	273	2.592 (0.8)	180	2.067 (1.0)	291
Excluding exiting vehicles	8.674 (6.4)	15	6.083 (5.7)	95	2.647 (0.8)	24	2.062 (1.6)	113

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.883 (1.0)	32	3.6	2.684 (0.6)	125
Excluding exiting vehicles	3.747 (1.7)	92	4.0	3.447 (1.2)	352

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	3.633 (1.3)	664	3.338 (1.2)	203	3.227 (1.2)	28
Excluding exiting vehicles	6.234 (1.9)	152	4.557 (2.8)	2	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





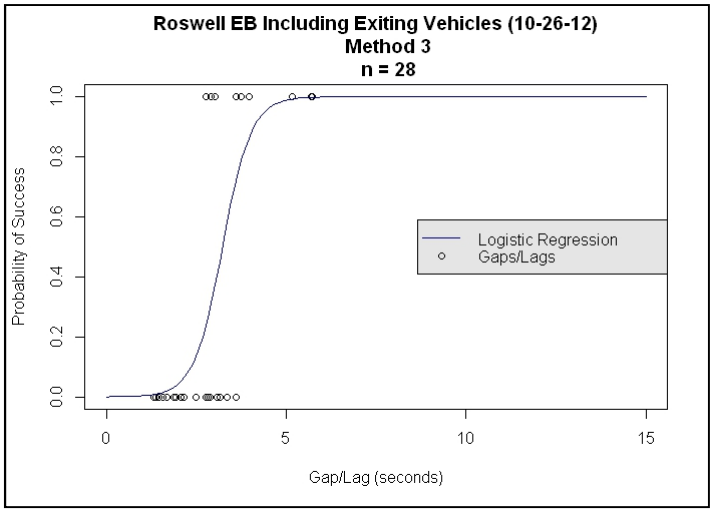
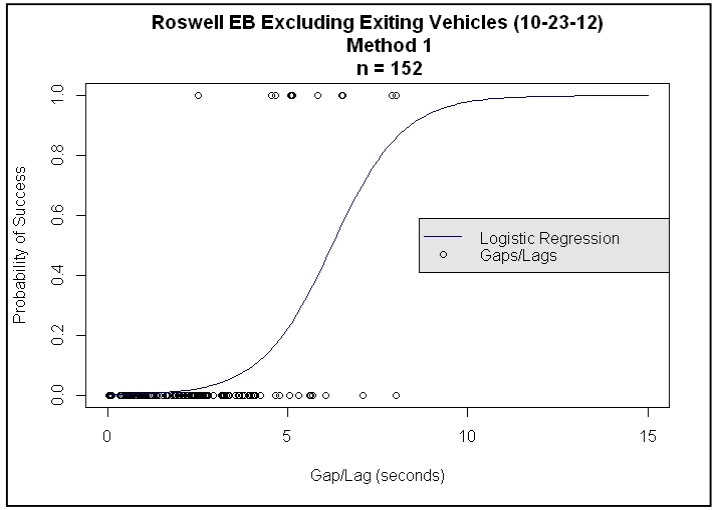


Figure 111. Critical headway including exiting vehicles for Roswell eastbound approach (10/23/12)



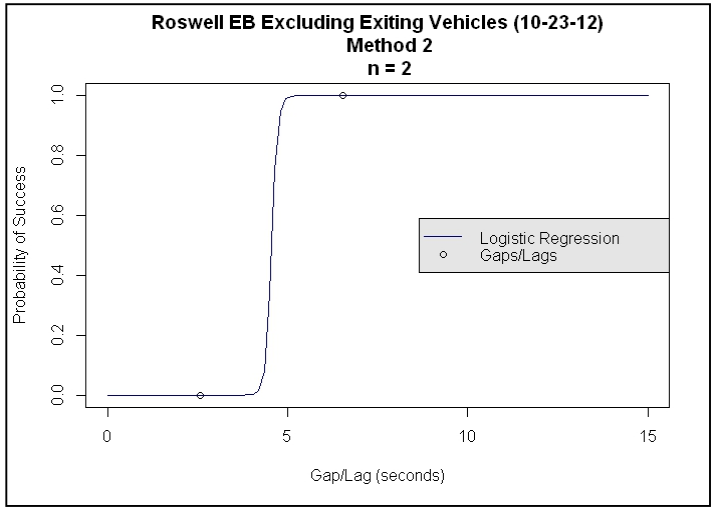


Figure 112. Critical headway excluding exiting vehicles for Roswell eastbound approach (10/23/12)

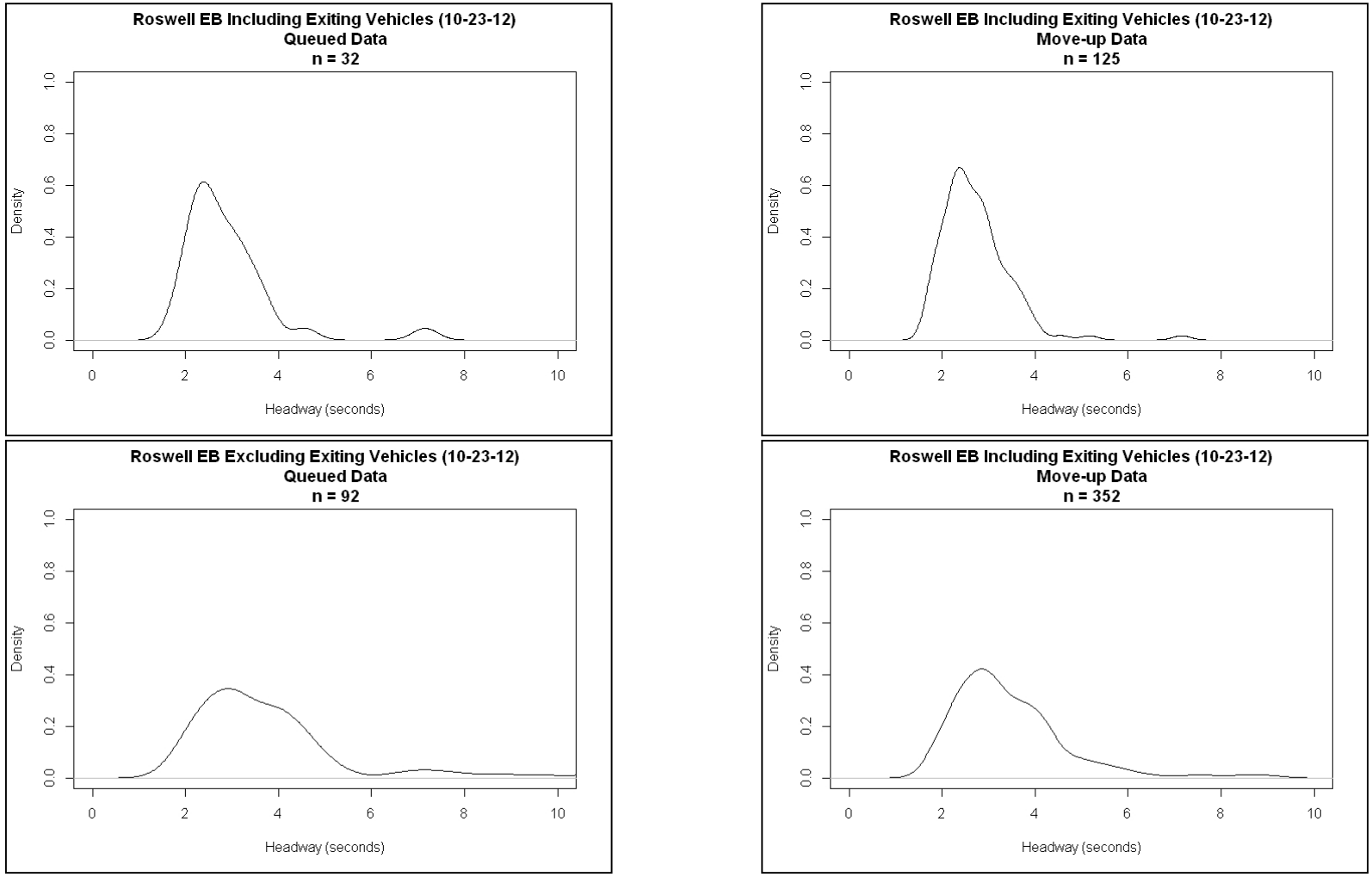


Figure 113. Follow-up headway for Roswell eastbound approach (10/23/12)

Table 47. Data summary sheet for Roswell southwestbound approach (10/23/12)

Site	Roswell		
ID	ROS02-SWB		
Approach	Southwestbound		
Intersection	Grimes Bridge Rd./Norcross St./Warsaw Rd./Medlody Ln.		
County	Fulton		
City	Roswell		
GDOT District	7		
AADT	n/a		
Date of data collection	Tuesday, October 23, 2012		
Time of data collection	3:37 PM – 5:16 PM		
Video duration	1:39:00		
Queuing periods at least 1 minute long	30		
Total number of queued minutes	43		
	Total data	vph data	
Number of entering vehicles	917	556	
Number of circulating vehicles	433	263	
Number of exiting vehicles	1166	707	

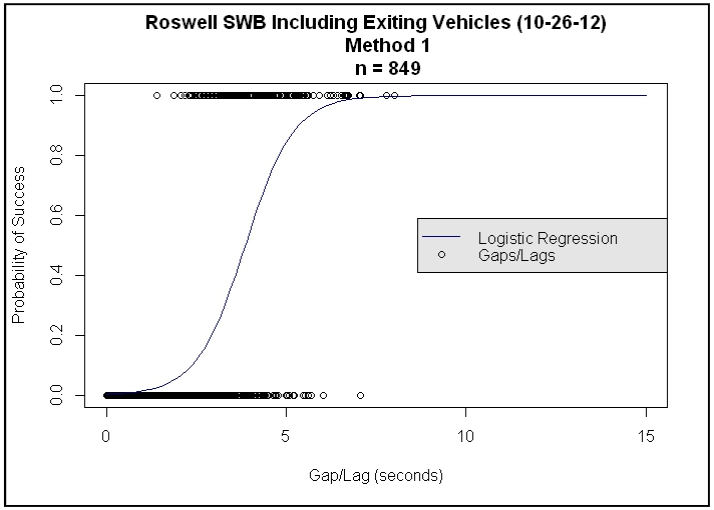
Source: Google Earth™, accessed 8/16/2013

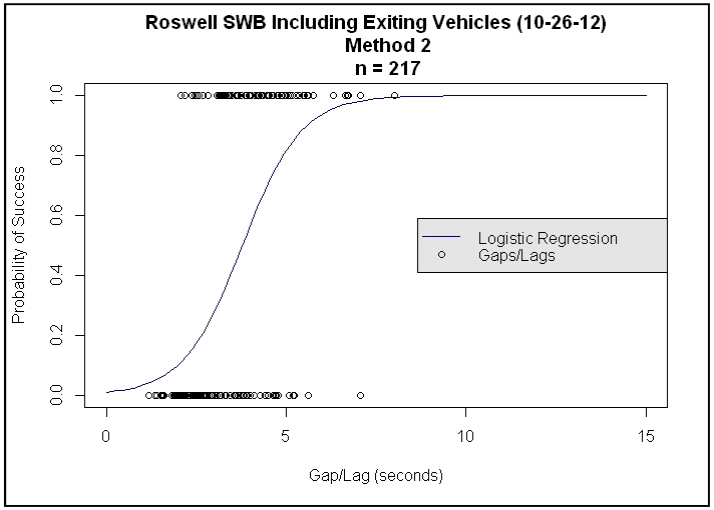
Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	4.395 (1.7)	199	3.626 (3.2)	214	2.732 (0.8)	259	1.593 (1.0)	391
Excluding exiting vehicles	5.101 (2.1)	134	4.841 (4.3)	161	2.794 (1.1)	187	1.620 (1.2)	339

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	2.926 (0.8)	248	3.6	2.762 (0.6)	267
Excluding exiting vehicles	3.249 (1.2)	336	4.0	3.061 (1.0)	351

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	3.863 (1.5)	849	3.780 (1.3)	217	3.648 (1.1)	132
Excluding exiting vehicles	4.443 (1.7)	660	4.064 (1.6)	112	4.032 (1.5)	58

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute





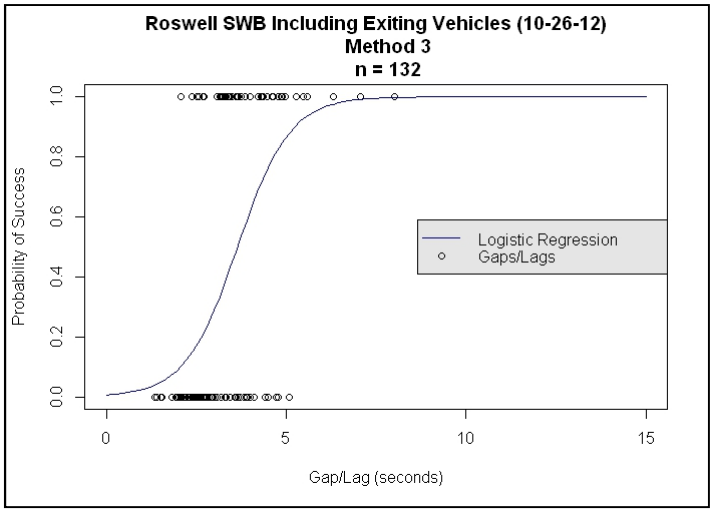
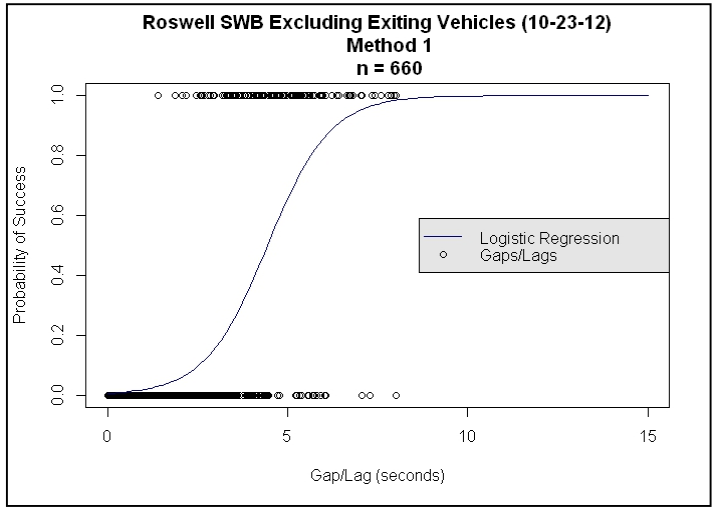
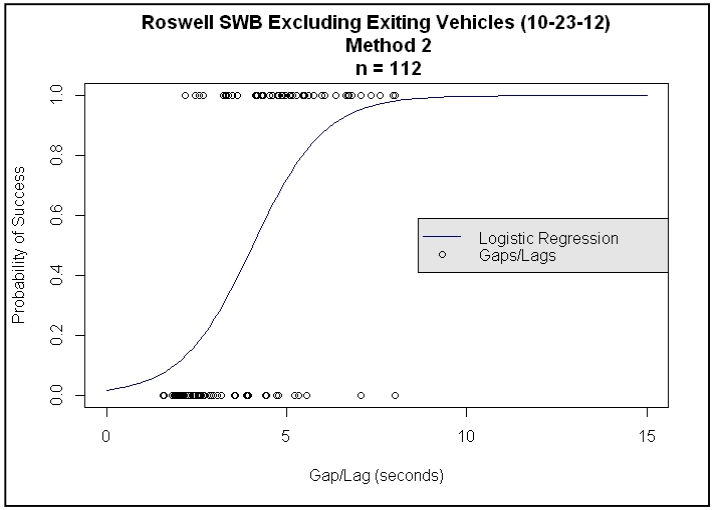


Figure 114. Critical headway including exiting vehicles for Roswell southwestbound approach (10/23/12)





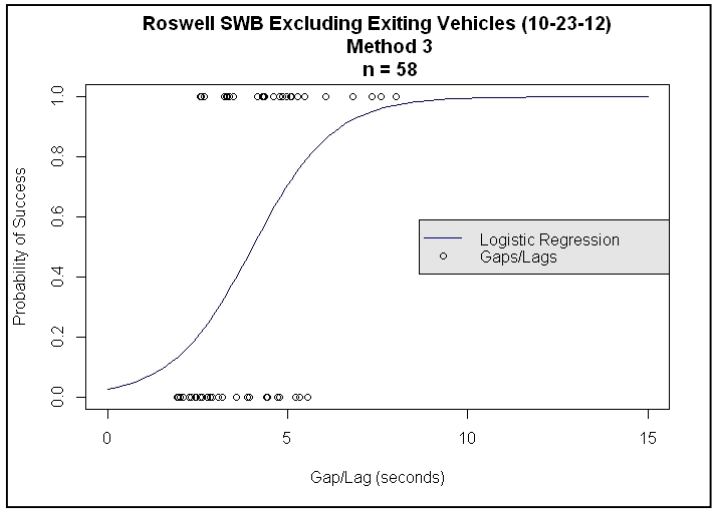


Figure 115. Critical headway excluding exiting vehicles for Roswell southwestbound approach (10/23/12)

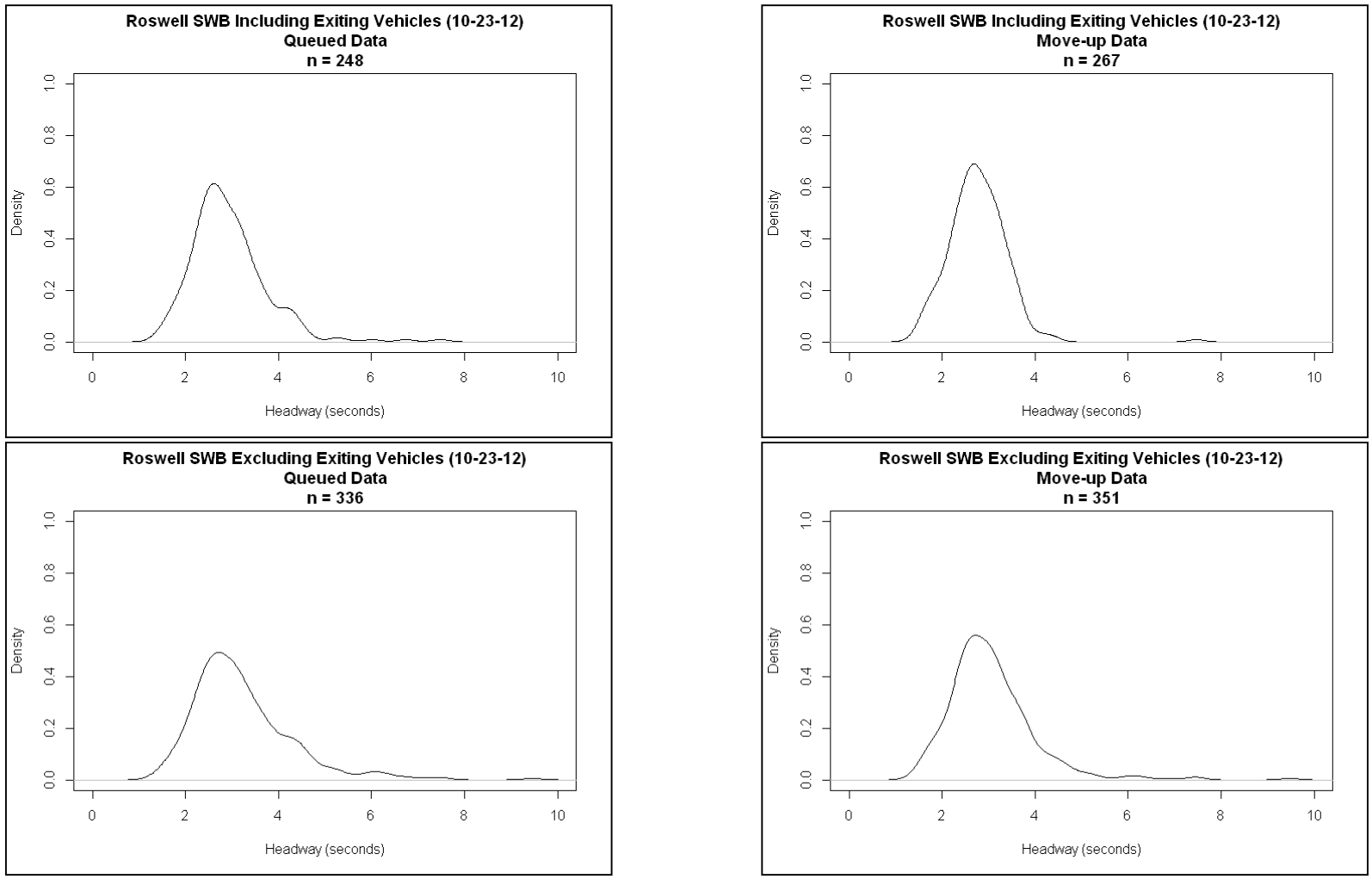


Figure 116. Follow-up headway for Roswell southwestbound approach (10/23/12)

Table 48. Data summary sheet for St. Simons westbound approach

Site	St. Simons		
ID	STS01-WB		
Approach	Westbound		
Intersection	Lawrence Rd./Frederica Rd.		
County	Glynn		
City	St. Simons Island		
GDOT District	5		
AADT	n/a		
Date of data collection	Saturday, July 28, 2012		
Time of data collection	2:20 PM – 4:26 PM		
Video duration	2:06:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	236	113	
Number of circulating vehicles	332	159	
Number of exiting vehicles	245	117	

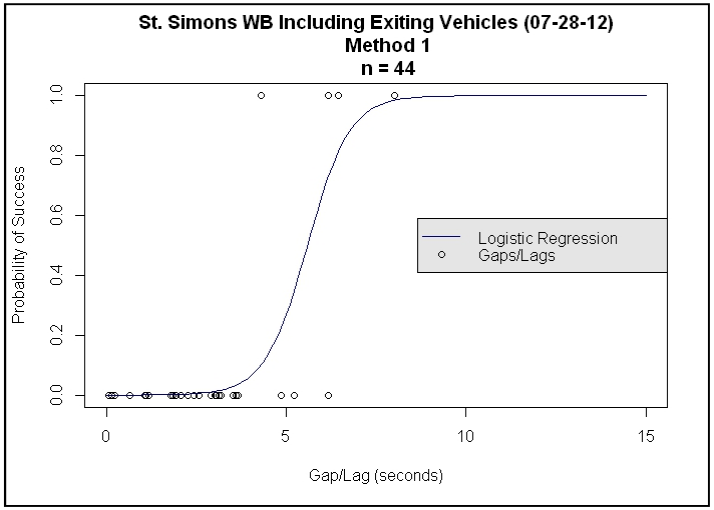
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	20.598 (13.3)	14	17.056 (14.9)	129	3.032 (0.9)	10	2.080 (1.6)	20
Excluding exiting vehicles	28.966 (26.5)	9	23.041 (19.6)	110	3.787 (2.1)	6	1.909 (1.8)	14

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.543 (0.6)	24
Excluding exiting vehicles	n/a (n/a)	0	4.0	2.843 (0.9)	30

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.587 (2.7)	44	5.517 (2.5)	15	n/a (n/a)	0
Excluding exiting vehicles	6.567 (3.0)	29	7.733 (2.6)	9	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



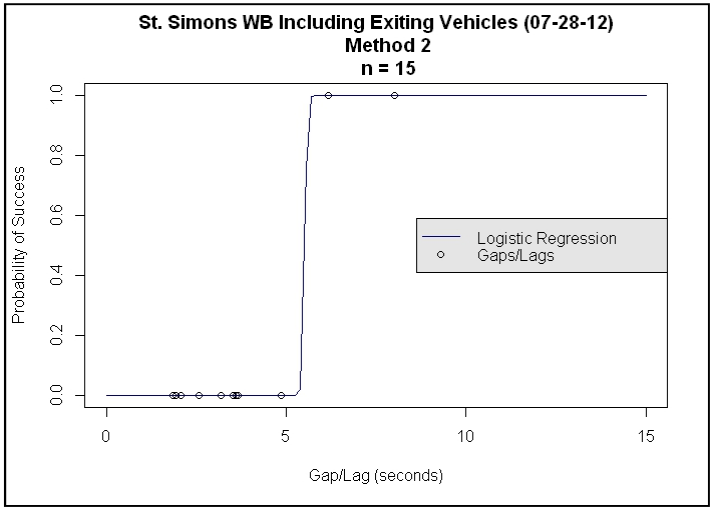
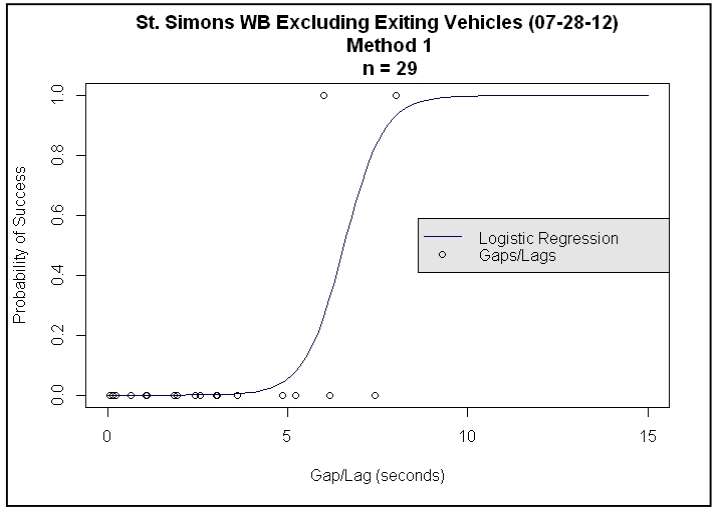


Figure 117. Critical headway including exiting vehicles for St. Simons westbound approach



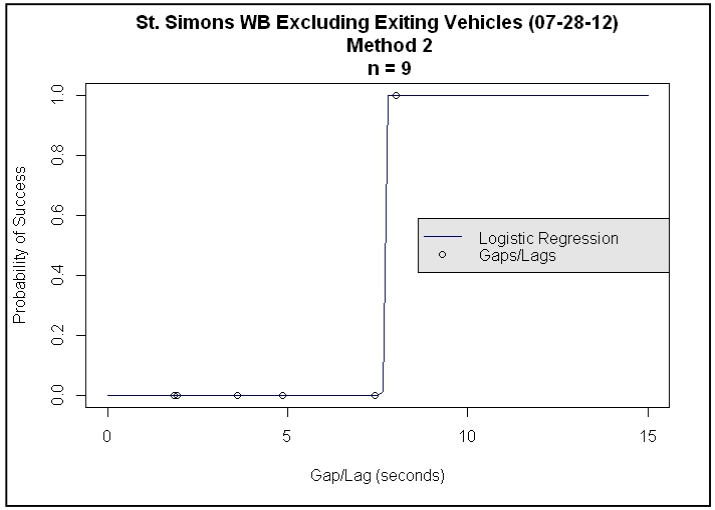


Figure 118. Critical headway excluding exiting vehicles for St. Simons westbound approach

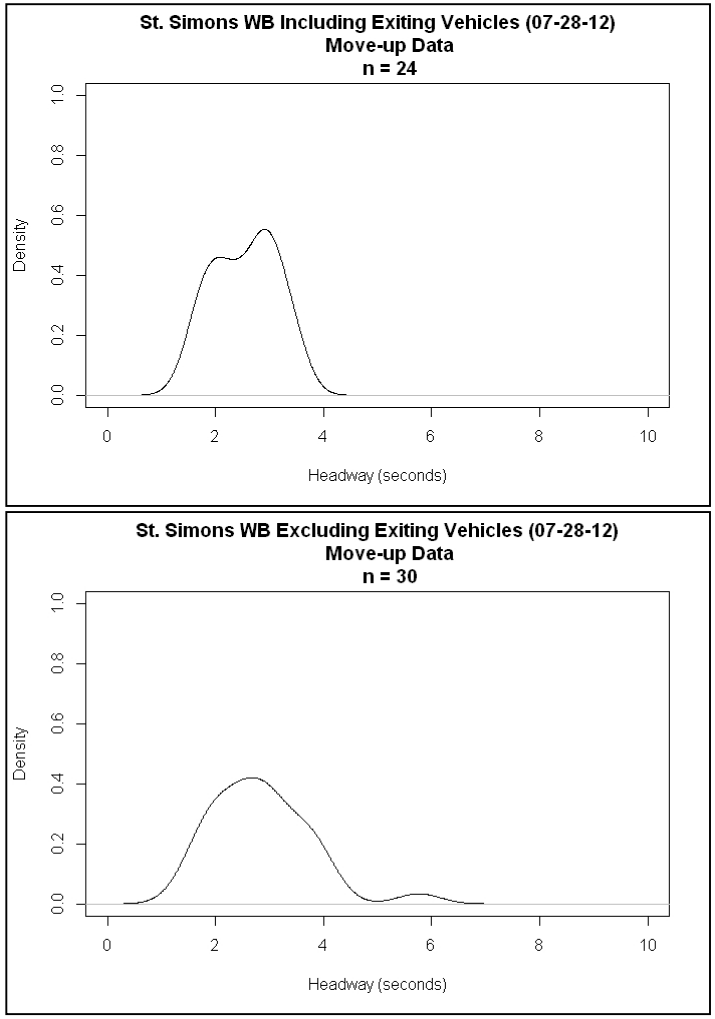


Figure 119. Follow-up headway for St. Simons westbound approach

Table 49. Data summary sheet for St. Simons eastbound approach

Site	St. Simons		
ID	STS01-EB		
Approach	Eastbound		
Intersection	Lawrence Rd./Frederica Rd.		
County	Glynn		
City	St. Simons Island		
GDOT District	5		
AADT	n/a		
Date of data collection	Saturday, July 28, 2012		
Time of data collection	2:23 PM – 3:32 PM		
Video duration	1:09:00		
Queuing periods at least 1 minute long	0		
Total number of queued minutes	0		
	Total data	vph data	
Number of entering vehicles	273	238	
Number of circulating vehicles	186	162	
Number of exiting vehicles	261	227	

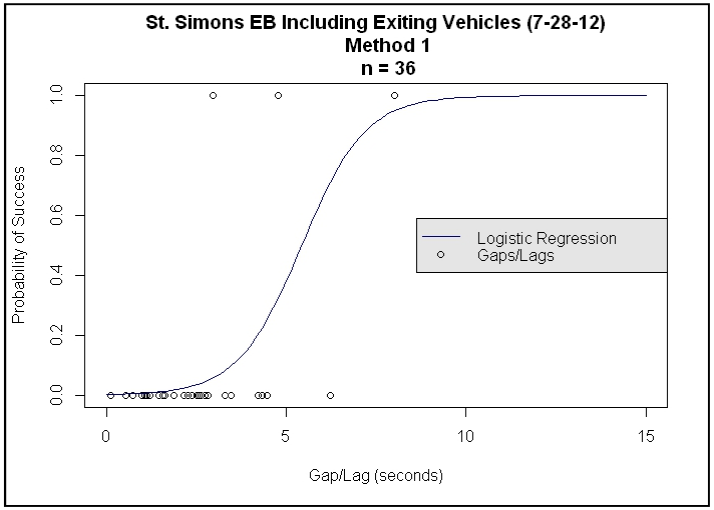
Source: Google Earth™, accessed 8/16/2013

Gap/Lag Data	**Accepted gaps**		**Accepted lags**		**Rejected gaps**		**Rejected lags**	
	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n	avg. (std. dev.) (s)	n
Including exiting vehicles	17.255 (11.9)	9	13.596 (11.5)	144	3.144 (1.5)	9	1.843 (1.1)	18
Excluding exiting vehicles	29.176 (13.7)	4	21.459 (17.7)	97	3.224 (1.7)	6	1.866 (1.5)	9

Follow-up Headway	**Queued Data**		**Move-up Data**		
	t_f (std. dev.) (s)	n	Move-up time (s)	t_f (std. dev.) (s)	n
Including exiting vehicles	n/a (n/a)	0	3.6	2.321 (0.9)	33
Excluding exiting vehicles	n/a (n/a)	0	4.0	2.519 (1.0)	37

Critical Headway	**NCHRP Method 1**		**NCHRP Method 2**		**NCHRP Method 3**	
	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n	t_c (std. dev.) (s)	n
Including exiting vehicles	5.431 (2.5)	36	6.030 (2.9)	9	n/a (n/a)	0
Excluding exiting vehicles	7.079 (2.7)	19	n/a (n/a)	0	n/a (n/a)	0

Legend: avg. = average; n = number of observations; tc = critical headway; std. dev. = standard deviation
[1]Follow up headway observations during all user defined queuing periods > 1 minute
[2]Follow up headway observations determined using move-up time thresholds from > 1 minute user defined queuing periods of all roundabouts
[3]Observations of gap acceptance (accepted/rejected gaps and rejected lags)
[4]Observations that include a rejected gap
[5]Observations that include a rejected gap and occur during user defined queuing periods > 1 minute



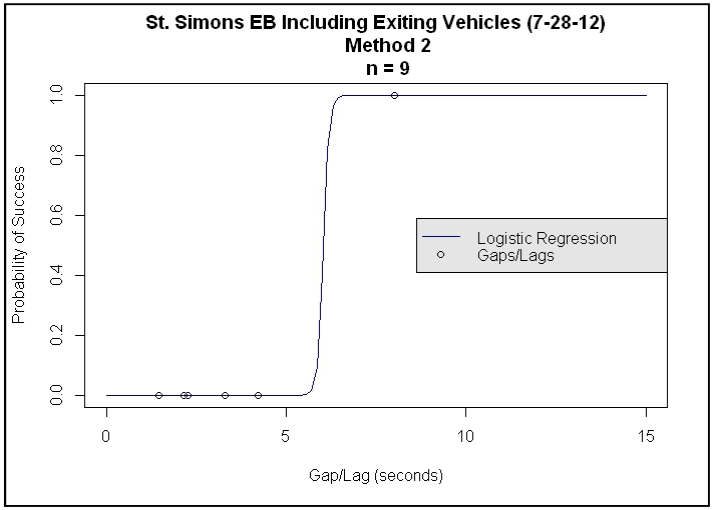


Figure 120. Critical headway including exiting vehicles for St. Simons eastbound approach

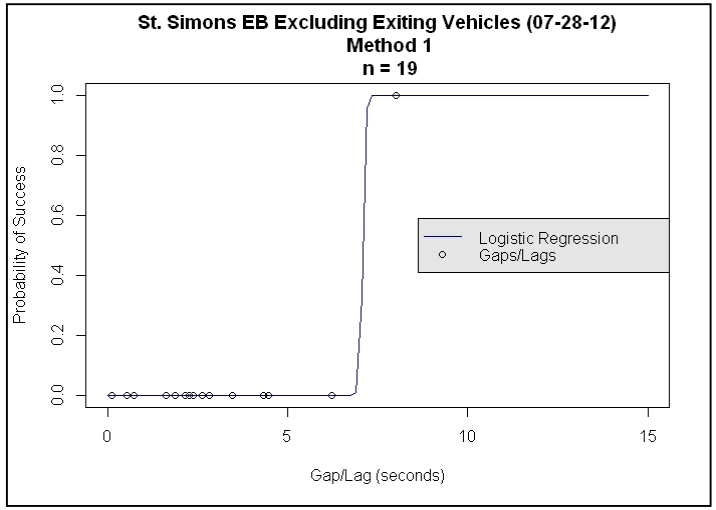


Figure 121. Critical headway excluding exiting vehicles for St. Simons eastbound approach

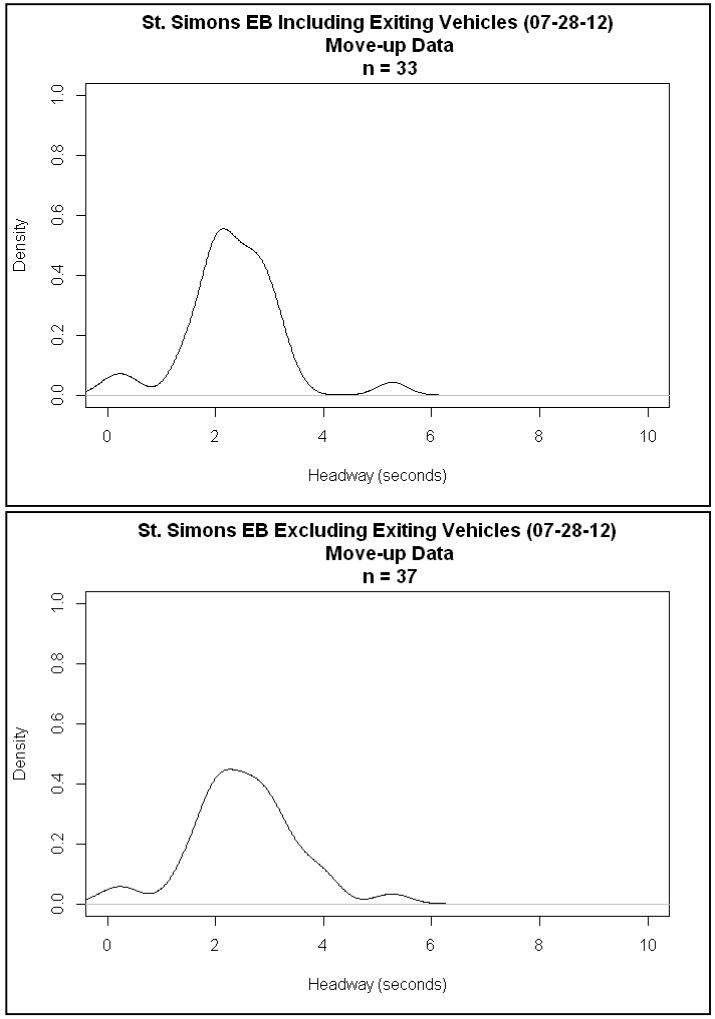


Figure 122. Follow-up headway for St. Simons eastbound approach

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